SOME PROPERTIES OF FLYASH FOR MINE BACKFILLING

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENT FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY
IN
MINING ENGINEERING

BY

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DEPARTMENT OF MINING ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA - 769008

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2013

National Institute Of Technology, Rourkela

CERTIFICATE

This is to certify that the thesis entitled **"SOME PROPERTIES OF FLYASH FOR MINE BACKFILLING"** submitted by **SUNDEEP CHOUDHARY** in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Mining Engineering at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Date: **Prof. M. K. Mishra**

Dept. of Mining Engineering

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SUNDEEP CHOUDHARY

109MN0591

CONTENTS

Certificate	(ii)
Acknowledgement	(iii)
Contents	
Abstract	(iv)
List of figure	(vii)
List of tables	(viii)

CHAPTER 1 INTRODUCTION

1.1	Background	2
1.2	Problems Associated With Fly Ash Generation	4
1.3	Need for Utilization of Fly Ash	5
1.4	Aim and Objective	6
1.5	Methodology	6
1.6	Organization of the thesis	7

CHAPTER 2 LITERATURE REVIEW

2.1	Introduction	10
2.2	Flyash generation and collection	10
2.3	Fly ash	11
2.4	Characterization of fly ash	13
2.5	Status of utilization of fly ash	15
2.6	Geotechnical properties	16
2.6.1	Compaction Test	16
2.6.2	Slump Cone Test	17
2.6.3	Brazilian Tensile Strength Test	17
2.6.4	Triaxial Compression Test	17
2.6.5	Ultrasonic Pulse Velocity Test	18

CHAPTER 3 METHODOLOGY

3.1	Methodology	21
3.2	Sample collection	21
3.3	Methods and Materials	21
3.4	Fly ash composite characterization	22
3.4.1	Compaction Test	22
3.4.2	Slump Cone Test	23
3.4.3	Brazilian Tensile Strength Test	24

3.4.4 Triaxial compression Test 25
3.4.5 Ultrasonic pulse velocity Test 26

CHAPTER 4 RESULTS AND DISCUSSIONS

4.1 Introduction 29
4.2 Compaction Test 29
4.3 Slump cone Test 30
4.4 Brazilian Tensile Test 31
4.5 Triaxial Compression Test 32
4.6 Ultrasonic pulse velocity test 36

CHAPTER 5 NUMERICAL INVESTIGATION

5.1 Numerical investigation 38

CHAPTER 6 SUMMARY AND CONCLUSION

6.1 Conclusion 49
6.2 Recommendation for future work 50

REFERENCES 51

ABSTRACT

Back filling of mine voids is mandatory to avoid subsequent ground stability problems in the form of subsidence. Mill tailings and river sand are being extensively used since a long time as mine back filling materials. However strict regulation and unavailability of river sand has created a huge problem for mining industry in India. The need to develop alternative engineering material which can substitute sand has gained prominence. Large quantities of fly ash discharged from coal-fired power stations are a major problem not only in terms of scarcity of land available for its disposal, but also in psychology as well as environmental aspects. Amount of fly ash available can be recycled, mainly by adding fly ash to cement. However, the addition of fly ash to cement is limited because the production rate of cement is limited, and also the concentration of fly ash in cement is limited. In the present study three fly ash composite materials (FCMs) were developed from the fly ash obtained from a nearby captive thermal unit. The main constituent of the composite were fly ash, lime, gypsum and cement. Detailed physical and engineering properties were determined for the FCMs. Significant increases in the compressive strength were obtained after 28 days of curing time and it was observed that the fly-ash composite developed has potential to be used as substitute to sand for back filling the mine voids.

List of figures

S.No	List of figure	Pg. No
1.1	Flow chart of the methodology	7
2.1	Coal ash generation from a pulverized coal-fired boiler	11
2.2	Fly ash	12
2.3	Comparison of fly ash particles to those of several soils.	13
2.4	Progressive utilization of flyash in cement industry during the period 1998-99 to 2010-11.	16
2.5	Typical arrangement of Ultrasonic velocity measurement	18
3.1	Standard Proctor Mould and Hammer	22
3.2	Slump test apparatus.	23
3.3	Setup for Brazilian tensile test in standard loading machine	24
3.4	Triaxial apparatus	25
3.5	Typical Ultrasonic velocity measurement device velocity	26
4.1	Graph between Dry density and Water content	30
4.2	Slump height vs. fly ash composite material	31
4.3	Slump height of flyash-cement composite material	31
4.4	Failure profile of different fly ash composite material	32
4.5	Triaxial characteristic of fly ash–lime composite material.	33
4.6	Triaxial characteristic of fly ash–gypsum composite material.	34
4.7	Triaxial characteristic of fly ash–cement composite material.	35
4.8	P-wave velocity of fly ash-lime, fly ash-gypsum and fly ash-cement composite materials.	37
5.1	Flow chart of modeling procedure.	40
5.2	Vertical Deformation in the gallery next to goaf edge without backfilling.	42
5.3	Vertical Deformation in the gallery next to goaf edge after backfilling with mixture of flyash with 4% limestone.	42
5.4	Vertical Deformation in the gallery next to goaf edge after backfilling with mixture of flyash with 4% gypsum	43
5.5	Vertical Deformation in the gallery next to goaf edge after backfilling with mixture of flyash with 4% cement.	43
5.6	Vertical stress developed over the goaf after backfilling with mixture of	44

flyash with 4% limestone.
5.7 Vertical stress developed over the goaf after backfilling with mixture of flyash with 4% gypsum. 44
5.8 Vertical stress developed over the goaf after backfilling with mixture of flyash with 4% cement. 45
5.9 Horizontal stress developed around the goaf after backfilling with mixture of flyash with 4% limestone 45
5.10 Horizontal stress developed around the goaf after backfilling with mixture of flyash with 4% gypsum. 46
5.11 Horizontal stress developed around the goaf after backfilling with mixture of flyash with 4% cement. 46
5.12 Effect of different composite backfilling material on vertical stress 47
5.13 Effect of different composite backfilling material on Horizontal stress 47
5.14 Effect of different composite backfilling material on vertical deformation 48

List of tables

S.No	List of tables	Pg no
1.1	Diseases due to the presence of heavy metals in fly ash	4
2.1	Chemical characteristic of fly ash	14
2.2	Physical characteristic of fly ash	14
2.3	Share of fly ash in various sectors	15
4.1	Water content determination	29
4.2	Dry density determination	29
4.3	Cohesion and friction angle of different fly ash composite material	32
4.4	Dynamic properties of fly ash	36
5.1	Properties of coal	41
5.2	Geo-mining condition of the mine	41
5.3	Engineering properties of fly ash composite material (FCM)	41

Chapter 1: Introduction

1.1 BACKGROUND

India is expected to produce more than 2, 50, 000MW during 12th five year plan period. The coal production will go up from 550 MT to 1000 MT per year. Large underground voids that are left out because of the mining operations have been creating various types of ground stability problems in many mining areas in India. Mine subsidence is a manifestation of the action of the gravity on strata which have been rendered unstable by the withdrawal of their natural support over a sufficiently large area. The strata sink slowly at different rate from seam to surface, until there is development in opposing forces which restore the equilibrium at the lower level. Subsidence is a very common phenomenon in many coal mining areas. The states of equilibrium of the strata are disturbed as soon as the excavation is done, different forces starts acting on it. The beds move downwards which temporarily frees them of the weight of the beds above it and the weight of the strata above the roadways is transferred to the coal pillars.

As the depth of mining increases, the area affected by subsidence also increases. The magnitude of maximum subsidence can reach an average of 90% of the seam thickness and in some situation it can be greater than the thickness of the seam [7]. There is almost full extraction of the seam in longwall mining, hence subsidence is a regular and is generally more than in bord and pillar working. Extraction in never full in bord and pillar working and stocks or pillars are left in the goaf which hinder and settlement and subsidence. A good number of the subsidence problems have been reported to have occurred suddenly and under built up areas which has resulted in collapse of the buildings and fatalities. Subsidence problems often remain as serious threats to the subsequent development of townships. Ground subsidence causes damage to surface structures such as buildings, railway track, sewers, canals, roads, etc. The greatest damage occurs where the curvature is maximum and not necessarily where the maximum subsidence occurs.

Mine backfilling has demonstrated to be an attractive option bulk utilization of fly ash for those plants located near the coal mine. Backfilling or sand stowing has been the technique followed for decades to counter the ground subsidence problem as well as to improve pillar recovery. In a mine in Jharia coalfield with hydraulic sand stowing it has been possible to work a coal seam 7.5 m thick below a railway line without any adverse subsidence effects [7]. Some of the common types of materials used for backfilling are mill tailings, waste rock, quarried rock, sand and gravel.

It is often observed that sand or mill tailings remain loose as backfilling material and merely serve as a temporary working platform and do not offer any lateral stress on the opening walls to improve the stability situation.

Cemented backfills are very costly and cost around 10%-20% of the total operating cost of the mines with cement representing 75% of that cost [1]. One of the major concerns of the mining industry is the unavailability of river sand for mine backfilling and because of it mine planner around the world are emphasizing on developing an alternative material to sand .Indian regulatory restrictions on sand mining for back filling are due to be implemented very soon. With the Ministry Of Environment & Forest (MOEF), Government of India making it mandatory to use flyash in backfilling of underground and open cast mines within 50km (by Road) of a thermal power plant it is high time for the mine planner and operators to take flyash as alternative to sand backfilling . Fly-ash is produced in large quantities from the thermal power plants in India. The current fly ash production is about 180 MT that will go up to about 600 MT by 2030 [8]. The usage percentage of fly ash is about 50% leaving the rest as plant waste occupying huge land area and creating environmental problems. There are numerous successful case histories on the utilization of fly ash either alone or mixed with lime, gypsum or both. Flyash is used in remote filling of mine voids both hydraulically and pneumatically. It main constituent is spherical glass nodules. These nodules make flyash an excellent material for remote filling as they can tend to roll over one another and result in low angle of repose. Typically fly ash has been used for soil stabilization, as embankment material, structural fill, for injection grouting, as a replacement to cement, in coastal land reclamation and in roads and embankments. They have also been successfully used as fly ash–cement mixture for subsidence control. It has also been reported that the use of pulverized fly ash filling had effectively stabilized the coal pillars thus reducing the risk of pillar failure in areas of low safety factor. The percentage of extraction also increases with the backfilling of the mine. Fly ash grout injection is being considered for use at closed underground mine as the injection would reduce acid mine drainage (ADM) by neutralizing AMD and by preventing contact between water and pyritic materials.

In the present investigation fly ash was mixed with additives such as lime, gypsum and cement at 4 % by weight to form a fly ash composite material to develop an alternative material for backfilling mine voids. The primary objective has been to achieve setting properties to the back fill material, so that it can develop compressive strength to offers lateral stress to the surrounding walls and pillars and can effect in increasing the stability of the opening. Numerical investigation was undertaken which showed that flyash composite material offered lateral stress to the surrounding and thus increasing the stability of the opening.

1.2 PROBLEMS ASSOCIATED WITH FLY ASH GENERATION

India is 3rd largest producer of coal in the world and has 4th largest reserve in the world. The major problem associated with fly ash is that its disposal not only requires large quantities of land, water and energy but its fine particles, if not managed properly, can become airborne and cause environmental hazard. India currently produces 160 MT of fly ash annually. Around 300 km^2 of land is being occupied by flyash ponds. Such a huge quantity of flyash poses challenges not only in the form of land use but also for health hazards and environmental damages. Since coal currently accounts for 70 % of the power generation of the country, there is an urgent need of new and innovative methods for reducing it environment impact. The problems associated with fly ash are given below.

1. It is very hard to handle fly ash in dry state as; it is very fine and readily airborne even in mild wind.
2. It pollutes air, water and disturbs the ecology of the surrounding atmosphere.
3. Flying fine particles of ash poses problems for people living near power stations. It also corrodes structural surfaces and affects horticulture.
4. Eventual settlement of fly ash particles over many hectares of land in the vicinity of power station brings about perceptible deterioration in soil characteristics.
5. Inhalation of fly ash can causes silicosis, fibrosis of lungs, bronchitis, pneumonitis etc.

Table 1.1: Diseases due to the presence of heavy metals in fly ash

Metal	Content (ppm)	Possible Diseases
Chromium (Cr)	136	Cancer
Nickel (Ni)	77.6	Respiratory Problem, Lung Cancer
Lead (Pb)	56	Anemia
Arsenic (As)	43.4	Skin Cancer, Dermatitis
Antimony (Sb)	4.5	Gastroenteritis
Cadmium (Cd)	3.4	Anemia, Hepatic Disorder

1.3 NEED FOR UTILIZATION OF FLY ASH

Considering that the 12th five year plan 2, 50,000 MW of electricity would be produced which will require coal production of 1000 MT. Consequently, fly ash generation shall touch the 600 million tonne / year mark by year 2030. Though the state of Orissa is not thickly industrialized, the fly ash generation in the state is about 93 lakh tones per annum. As far as thermal power sectors in Orissa are concerned only about 22.6% of fly ash is being utilized. If this trend continue in future may require large amount of land area for disposal of fly ash.

According to Central Electricity authority of India, there are around 86 major coal fired thermal power plants. There are more than 1800selected industrial units which had captive thermal power plants generating more than 1 MW of electricity.

Present Scenario on Fly Ash in India

- Around 66 % of the total installed power generation is thermal
- 350-400 million MT coal is being used every year
- High ash contents varying from 30 to 50%
- More than 180 million MT of ash generated every year
- Ash generation likely to reach 600 million MT by 2030
- As per the Ministry of Environment & Forest Figures, 30% of Ash is being used in Fillings, embankments, construction, block & tiles, etc.

The fly ash produced as a result of burning of Indian coal has great potential to be utilized for different applications.

The current percentage of utilization of fly ash in India is very low when compared to the other countries like Germany, Netherlands etc where the utilization is above 90 %. As nearly 66% of the country’s total installed power generation capacity is thermal of which coal-based generation is 90%. Some 86 major thermal power stations and several captive power plants use bituminous and sub-bituminous coal and produce large amount of fly ash. High ash content (30% - 50%) coal contributes to these large volumes of fly ash. Also the country’s dependence on coal for power generation has unchanged. Thus fly ash management has become a major cause of concern for the future.

1.4 AIM AND OBJECTIVES

The aim of the investigation was to reduce the problem of subsidence so as to protect the surface feature by mine void backfilling as well as effective utilization of flyash. The specific objectives to meet the goal were the following.

1. Characterization of fly ash.
2. Determination of geotechnical properties of fly ash composite material.
3. Development of composite materials with fly ash, lime, gypsum and cement at their respective OMC-MDD.
4. Determination of geotechnical properties such as, Unconfined Compressive Strength (UCS), Brazilian Tensile Strength (BTS) and Ultrasonic P wave velocity.
5. Determination of stress and convergence over stowed area using flyash composite material through simulation of numerical modeling.

1.5 METHODOLOGY

Almost all thermal power plants are usually located near the coal mines so as to reduce the transportation cost of coal. They produces large amount of flyash and its disposal is a major problem and cause environmental problems. Flyash has many geotechnical applications. But its effective utilization in the area of mine backfilling is still to be explored. With the government of India making it mandatory for utilization of flyash in mine backfilling, this area has started receiving attentions.

The present study focuses on the use of the fly ash based composite materials for mine backfilling and evaluate its performance in reducing the convergence. The outcome of the research would be useful in reducing the subsidence problem of underground mines as well as increasing the prospect of utilization of flyash. This investigation was an attempt to utilize fly ash in different compositions with lime, gypsum and cement to enhance the strength of the flyash. The overall approach adopted to attain the various objectives to achieve the goal is outlined below.

a. Review of available literature to critically obtain information on mine backfilling, on geotechnical properties of fly ash, on strength enhancing materials etc.
b. Development of experimental setup and characterization of ingredients.
c. Development of composite material with fly ash-lime, flyash-gypsum, flyash-cement.

d. Determination of geotechnical properties of the developed composites by performing the tests and analyses as Moisture Density relationship, Slump cone test, Triaxial test, Brazilian tensile strength, Ultrasonic pulse velocity.

e. Simulation to investigate the behavior of stresses over the stowed area.

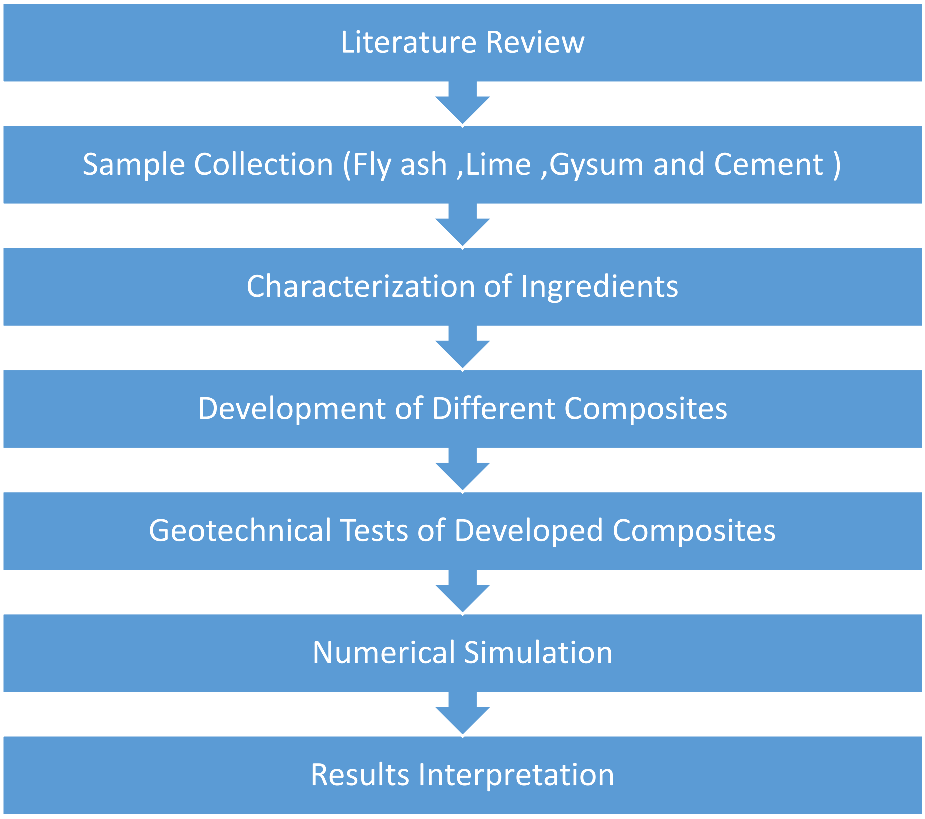

Figure 1.1: Flow chart of the methodology

1.6 ORGANIZATION OF THE THESIS

The thesis is covered in six chapters. The first chapter gives an introduction which includes Background of the research, Problems associated with fly ash generation, Need for utilization of fly ash, Aim and Objectives, and methodology of research work. Second chapter includes a detailed review of literature on fly ash, fly ash generation and collection, characterization and geotechnical properties as well as utilization of fly ash. The materials used and methods adopted for the examination including collection of ingredients, sample preparation and testing techniques used for characterization of ingredients as well as development of composite materials are described in details in chapter three. Result and discussion which include the result of geo-technical properties of developed composite materials are describe in chapter four. Numerical investigation to study the effectiveness of the developed composite materials on the stress behavior of the backfilled mines is described in Chapter five. Chapter six includes summary and conclusion of the investigation. At the end the literatures referred are given.

Chapter 2: Literature review

2.1 INTRODUCTION

Coal ash is the mineral residue that is obtained as a byproduct from combustion of pulverized coal at high temperatures and pressures in power stations.

There are three types of byproduct generated during coal combustion fly ash, boiler slag and bottom fly ash.

Fly ash is 75-80% of the total ash produced. An estimated 25% of fly ash in India is used for cement production, construction of roads and brick manufacture.

2.2 FLYASH GENERATION AND COLLECTION

The fly ash produced from the burning of pulverized coal in a coal-fired boiler. Typically, coal is pulverized and blown with air into the boiler's combustion chamber. Where it ignites immediately generating heat and producing a molten mineral residue. Boiler tubes extract heat from the boiler, cooling the flue gas which causes the molten mineral residue to harden and form ash (Figure 2.1).

It is a fine material with spherical particles. It very much resembles volcanic ashes and also named as ‘Pozzolans’. Fly ash is generated from various organic and inorganic constituents present in feed coals and is produced at a temperature of 1200-1700^{0}C. Indian coal has high ash contents that vary from 30 to 50%.

The lighter fine ash particles are termed as flyash which remain suspended in the flue gas. While coarse ash particles, referred to as bottom ash or slag, fall to the bottom of the combustion chamber. Flyash is removed by particulate emission control devices such as electrostic precipitators or filter fabric baghouses.

The component of flyash vary considerably depending upon the source of the coal being burned, but all flyash includes substantial amounts of silicon dioxide and calcium oxide , both being endemic ingredients in many coal bearing rock strata.

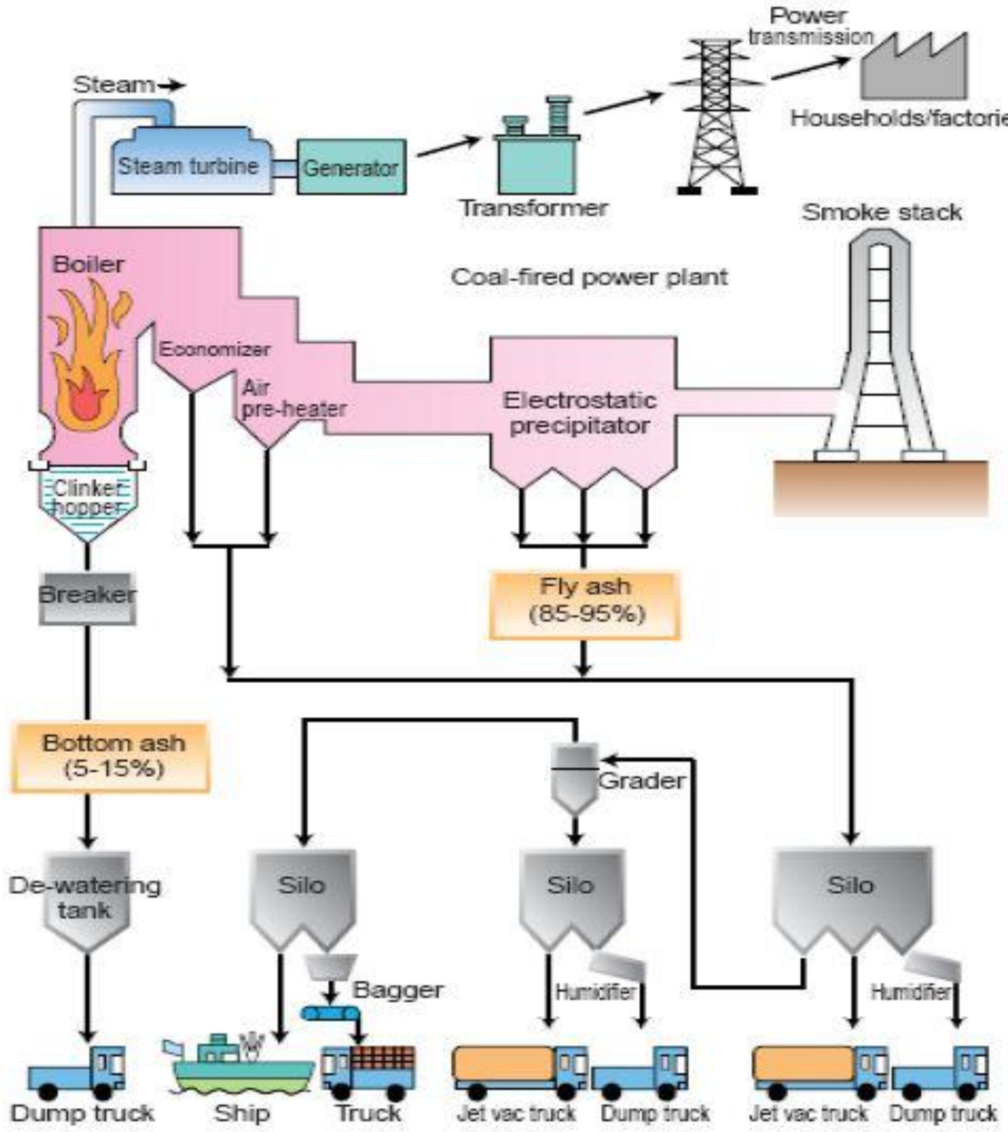

Figure 2.1: Coal ash generations from a pulverized coal-fired boiler [4]

About 80% of all the ash leaves the furnace as flyash. When pulverized coal is combusted in a wet-bottom (or slag-tap) furnace, 50% of the ash is retained in the furnace and the other 50 percent being entrained in the flue gas. In a cyclone furnace, where crushed coal is used 70 to 80 % of the ash is retained as boiler slag and only 20 to 30 % leaves the furnace as dry-ash in the flue gas.

2.2 FLY ASH

Fly ash is the finest of coal ash particles. It is called 'fly' ash because it is transported from the combustion chamber by exhaust gases. Fly ash is the fine particles typically from 0 to 50 µm, at times including that of 150 µm, formed from the mineral matter in coal, consisting of the non-combustible matter in coal and a small amount of carbon that remains from incomplete combustion of the coal.

Fly ash is generally grey in color, abrasive, typically alkaline and refractory in nature. Pozzolans, which are siliceous or siliceous and aluminous materials that together with water and calcium hydroxide from cementitious products at ambient temperatures are also known as admixtures (Figure 2.2).

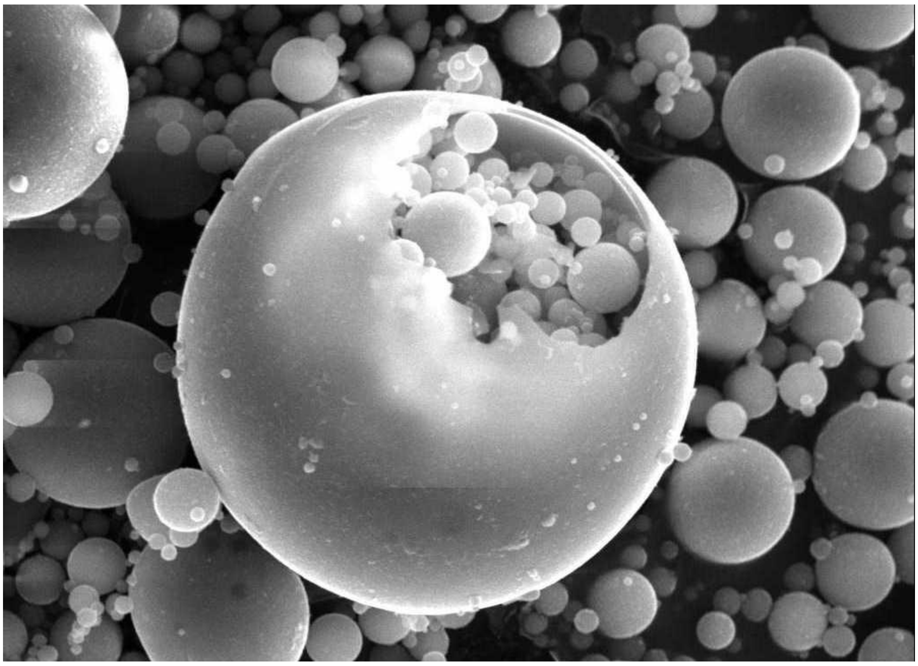

Figure 2.2: fly ash (http://geoinfo.nmt.edu/staff/hoffman/flyash.html)

The geotechnical properties of fly ash (e.g. specific gravity, permeability, and internal angular friction and consolidation characteristics) make it suitable for use in construction of roads and embankments.

The pozzolanic properties of the fly ash, including its lime binding capacity makes it useful for the manufacture of cement, building materials and concrete admixed products.

A comparison of fly ash particles sizes to those of several types of soils is presented in the Figure 2.3

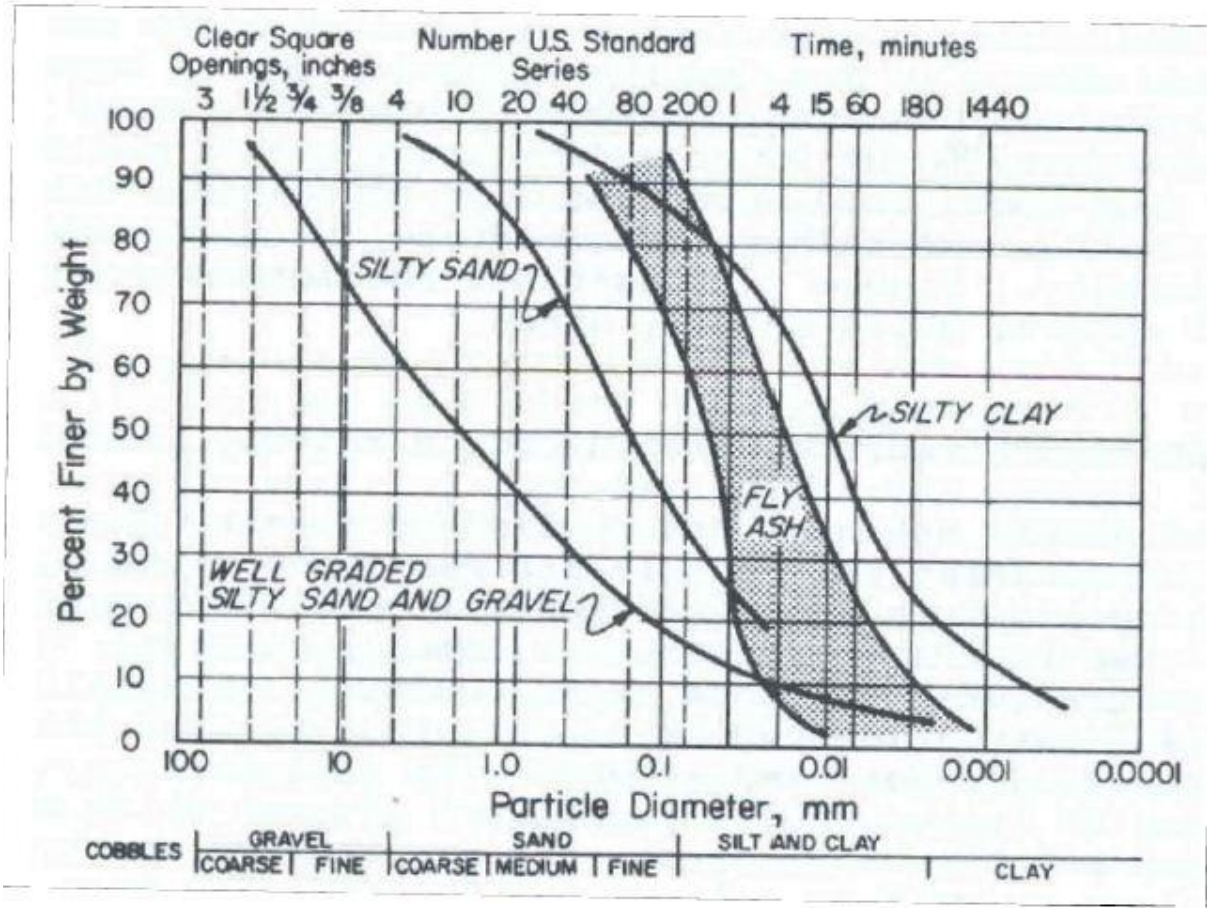

Figure 2.3: Comparison of fly ash particles to those of several soils (*Meyers et al, 1976*)

2.4 CHARACTERIZATION OF FLY ASH

Coal-based thermal power plants all over the world are facing serious problems handling and disposing the fly ash. The problem becomes more complex because of the high ash content (30–50%) of the coal in India. At present there are about 86 thermal power stations producing nearly 180 million tonnes of coal ash per annum. The requirement of large disposal area is a major cause of concerns so that it should not adversely affect the environment. Hence attempts are being made for its bulk utilization of the fly ash rather than dumping it. The coal ash is utilized in bulk only in geotechnical engineering applications such as a backfill material, construction of embankments, as a sub-base material, etc. An in-depth understanding of the physical, chemical, engineering and leaching behavior are required. This necessitates characterization of the fly ash with reference to geotechnical applications.

Table 2.1: Typical Chemical characteristics of fly ash [1]

Constituents	Percentage
Carbon	2.10
Volatile matter	0.147
Fe_2O_3	8.83
MgO	0.84
Al_2O_3	27.73
SiO_2	58.9
P_2O_5	0.17
SO_3	0.24
K_2O	0.79
CaO	1.11
Na_2O	0.14
TiO_2	2.09

Table 2.2: Physical characteristics of fly ash

Parameters	Value
Colour	Light gray
Dry density, kg/m^3	1.208 g/cm3
Optimum moisture content ,%	30
Permeability m/sec	$(3.5\text{-}3.7)^* \ 10^{-6}$
Liquid limit %	40.89
Plastic limit %	Non –plastic
Specific gravity	2.54

2.5 STATUS OF UTILIZATION OF FLY ASH

Fly ash has got various applications in several areas and hence treated as by-product and not as a waste. Due to pozzolanic property, it is used as raw material for cement manufacturing. Some of the other major areas of current fly ash utilization are back filling in opencast mines, reclamation of low lying areas, stowing in underground mines, manufacturing of bricks, construction of road and embankments, structural fills. The present utilization of fly ash is around 50%. Some of the applications include use of fly ash in mine backfilling, construction of roads/ flyover embankments, manufacture of several building components like bricks, tiles, blocks and use in agriculture.

Table 2.3: Share of fly ash in various sectors

Area of Utilization	Utilization(%)	Utilization (MT)
Manufacture of Cement	44	35
Construction of Road Embankments	19	15
Substitution of cement	12	10
Back Filling in Mines	9	7
Reclamation of low lying Areas	7	6
Raising of Ash Dykes	4	3
Brick Manufacturing	4	3
Agriculture	0.5	0.5
Others	0.5	0.5

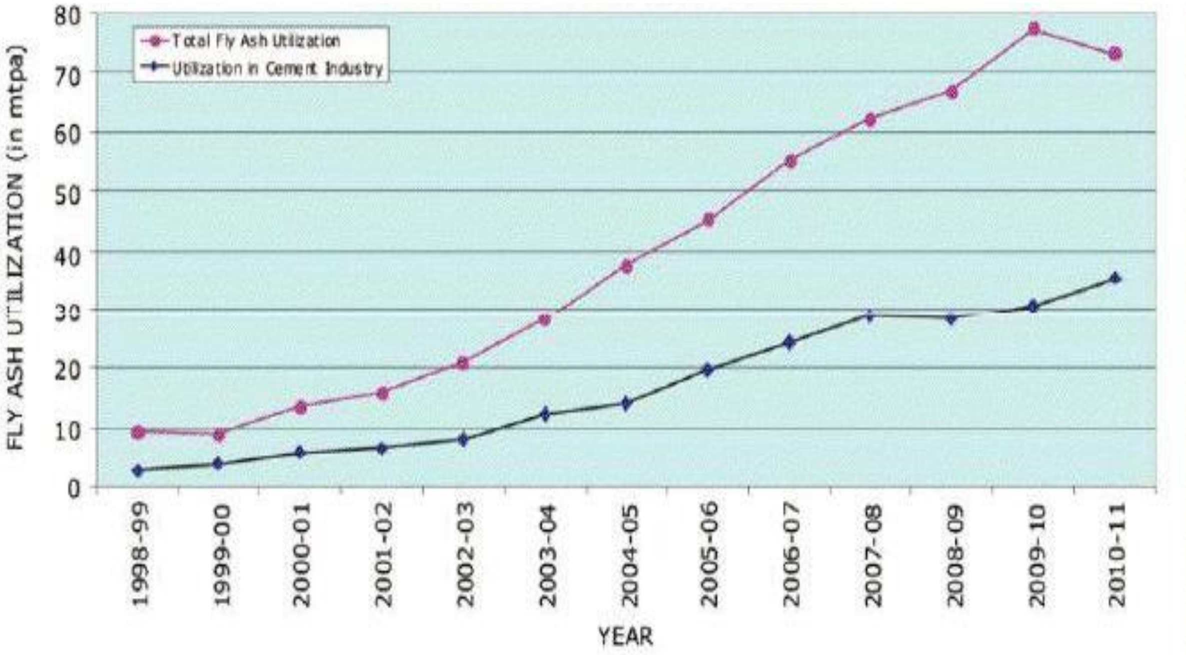

Figure 2.4: Progressive utilization of flyash in cement industry during the period 1998-99 to 2010-11 (CEA REPORT, 2011)

2.6 GEOTECHNICAL PROPERTIES

The success of any material depends on its properties. Fly ash has been used for its excellent geotechnical properties obtained with many additives. Some of those are discussed below.

2.6.1 COMPACTION TEST

Compaction of fly ash is required to improve its engineering properties. The compacted unit weight of the material depends on the amount of energy applied, plasticity characteristic, grain size distribution, and moisture content at compaction. Maximum dry density increases and Optimum moisture content decreases with increase in fineness of fly ash. The presence of porous particles e.g. (unburnt carbon, plerosphere and cenospheres) was responsible for high moisture content value. Variation of dry density with moisture content for fly ash is less compared to that for a well-graded soil; both have the same median grain size. Due to higher air void content fly ash is less sensitive to variation in moisture content than for soils. The higher void content tend to bound the buildup of pore pressures during compaction, thus allowing the fly ash to be compacted over a larger range of water content .

Gatti and Tripiciano (1981) stated that the obtained maximum dry density varied between 11.4 kN/m^3 and 45 kN/m^3 with the corresponding optimum moisture contents ranging between 28% and 36% by compaction tests that were carried out on coal ashes. Typically optimum moisture content is in the range 17.9% to 62.3% and maximum dry density of Indian fly ash vary in the range 8.9 kN/m^3 to 13.8 kN/m^3. Fly ashes originating from different sources themselves show large variations in OMC and MDD due to their specific gravity depends on carbon and iron contents. There are many standards available for the test and ASTM D698 is one of those.

2.6.2 SLUMP CONE TEST

The concrete slump test is an empirical test that measures the workability of fresh concrete. It measures the consistency of the concrete in that specific batch. This test is performed to check the consistency of freshly made concrete. Consistency is a term very closely related to workability. It refers to the ease with which the concrete flows. It is used to indicate the degree of wetness. There are many standards available for the test and ASTM C143 is one of those.

2.6.3 BRAZILIAN TENSILE STRENGTH TEST

Determination of direct tensile strength of a rock mass is difficult. So, indirect test is done to determine the tensile strength of the flyash composite materials i.e. Brazilian tensile test. The Brazilian tensile test make the sample fail under tension though the loading pattern is compressive in nature. There are many standards available for the test and ASTM D3967 is one of those.

2.6.4 TRIAXILA COMPRESSION TEST

In a triaxial compression test, a cylindrical core sample is loaded axially to failure, at constant confining pressure. The peak assessment of the axial stress is taken as the confined compressive strength of the sample. A triaxial compression system is used to carry out this type of testing. Axial load is applied with the help of a servo-controlled actuator. Pore pressure and confining pressure are hydraulically generated. In addition to axial stress, axial and radial strains can be monitored in this test, to determine elastic constants (Poisson's ratio,v and Young's Modulus, E). If triaxial test is performed at several confining pressures, and if tensile test data and unconfined compression test data are available, a locus representing failure can be constructed. The confining pressures for triaxial testing are generally spread over a range from very low to beyond the maximum expected in-situ effective stress conditions. Axial stress is monitored with the help of load cell. Pore pressure and Confining pressure are monitored with conventional pressure transducers. Radial strains and axial strains are measured using cantilever type strain transducers. When a rock is brittle, large deformation is expected. Occasionally, strain gages are attached directly to the sample. Tests can be conducted at temperatures up to 500° F. Outflow or inflow of pore fluid is measured with accumulators.

2.6.5 ULTRASONIC PULSE VELOCITY TEST

Ultrasonic pulse velocity analysis is a non-destructive testing method. It is used to determine the dynamic properties of materials. This method is applicable for wave velocity measurement of both isotropic and anisotropic materials though velocities obtained in anisotropic materials may be influenced by several factors such as direction, material composition, dampness, travel distance, weakness and diameter of transducer (Figure 2.5).

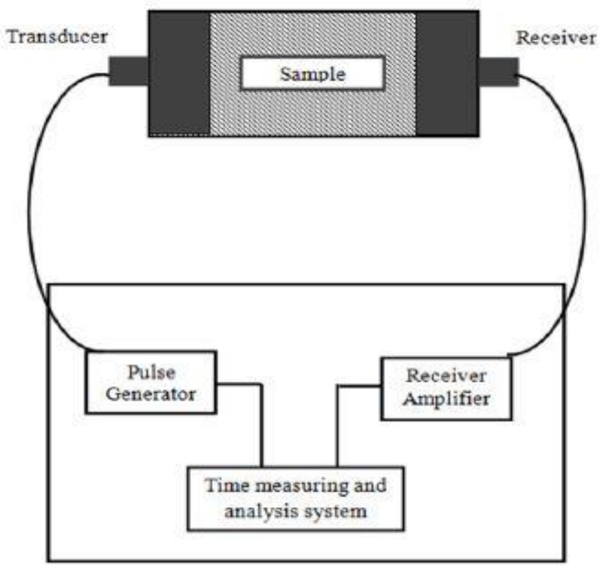

Figure 2.5: Typical arrangement of Ultrasonic velocity measurement

The ultrasonic velocity test is a measurement of transit time of a longitudinal vibration pulse through a sample which has a known path length. It is carried out by applying two transducers (receiver and transmitter) to the opposite end surfaces of the samples. If any discontinuity surface lies in the pulse path, the measured time corresponds to the pulse that follows shortest path, because any discontinuity causes a time delay compared to travel time of pulses in homogeneous mass. The electrical pulses of specified frequency are generated by pulse generator. These pulses are converted into elastic waves which transmit through the sample by transmitter. The mechanical energy of the propagating waves that transmit through the sample is received by the second transducer called receiver placed at opposite end of the sample. Then it turns it into electrical energy of same frequency. The signal travel time is measured electronically and is registered in the oscilloscope.

Chapter 3: Methodology

3.1 METHODOLOGY

The aim of the investigation was to enhance strength of fly ash composites material for backfilling of underground coal mine. This chapter presents methods adopted and materials used to accomplish the goal. The major ingredients were fly ash, lime stone, gypsum and cement. Sample preparation, various methods followed for characterization of ingredients and development of different composite materials are reported in this chapter.

3.2 SAMPLE COLLECTION

Fly ash, a by-product of coal combustion was collected from a nearby power plant. The plant is situated near the two major coalfields. It consumes 2230 tonne of coal per year and produces about 600 tonne of fly ash per year. The flyash is typically dumped in nearby pond area.

The fly ash used in the present study was collected in dry state from electrostatic precipitators of the plant. During the combustion of pulverized coal, the volatile matter is vaporized and the majority of the carbon is burnt. The mineral matter associated with the coal, such as quartz, clay and feldspar disintegrates. The finer particles that escape with flue gases are collected using electrostatic precipitators in a hopper. The hoppers have small outlets. Strong poly-coated cotton gunny bags of 50 kg capacity were used to collect the dry flyash. Each bag was sealed immediately after fly ash collection. The bags were then transported with care from the plant to laboratory and kept in a controlled environment.

3.3 METHODS AND MATERIALS

This section summarizes the procedures and materials used in performing the various tests of fly ash composite in order to utilize in Geotechnical Application of mine filling. This section describes the fly ash characterization methods and the method for preparing Lime -fly ash, gypsum-fly ash and cement –fly ash mix specimens. Fly ash occupies huge disposal area and has a potential threat of local ground water and surface water pollution by leaching of metal. To mitigate the problem is to recycle the fly ash as a safe composite material for mine backfilling and other purposes. Due to inherent self-hardening properties of fly ash it is used in different civil engineering applications. But it lacks adequate strength or durability. Appropriate mixture is one of the methods to enhance the strength of the fly ash.

3.4 FLY ASH COMPOSITE CHARACTERIZATION

Fly ash composite characterization test were performed on the fly ashes that were investigated in this project. Tests included compressive strength, tensile strength. In addition to this moisture content and true density of fly ash were found.

3.4.1 COMPACTION TEST

This test is performed to determine the relationship between the moisture content and the dry density of a soil for a specified compactive effort. This test will employ the tamping or impact compaction method using the type of equipment and methodology developed by R. R. Proctor in 1933, therefore, the test is also known as the Proctor test. ASTM D 698 - Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (600 KN-m/m^3) was used.

In Standard Proctor Test, the flyash is compacted by making a 2.5 kg hammer fall a distance of one foot into a flyash filled mold. The mold is filled with three equal layers of flyash, and each layer is subjected to 25 drops of the hammer.

Figure 3.1: Standard Proctor Mould and Hammer

The optimum water content is the water content that results in the greatest density for a specified compactive effort.

Water to add (ml) = flyash (gm)*0.16

1gm of water is equal to approximately one milliliter of water.

The mutual relations is given by the following equation.

$$\rho_d = \frac{\rho}{1+w}$$

ρ_d=dry density

ρ= wet density

W= moisture content in percentage

3.4.2 SLUMP CONE TEST (ASTM METHOD C143)

Determining the consistency of concrete by filling a conical mold with a sample of concrete, then inverting it over a flat plate and removing the mold; the amount by which the concrete drops below the mold height is measured and this represents the slump. This test method describes the procedure for determining the slump of fresh concrete mixtures.

Figure 3.2: Slump Test Apparatus

Test Procedure

- Dampen the mold and place it on a flat, non-absorbent, moist, rigid surface.
- Hold firmly in place.
- Fill the cone 1/3 full and uniformly rod the layer 25 times to its full depth.
- Fill the cone with a second layer until 2/3 full by volume and rod 25 times uniformly, ensuring that the rod just penetrates into the first layer.

- Overfill the cone with the third layer and rod uniformly, 25 times, with the rod just penetrating into the second layer.
- Strike off the excess concrete level with the top of the cone by a screening and rolling motion of the tamping rod.
- Remove any spilled fly ash from around the bottom of the cone.
- Immediately remove the mold from the fly ash by raising it carefully in a vertical direction without lateral motion.
- Measure the difference between the height of the mold and the height of the specimen at its highest point to the nearest millimeter. This distance will be the slump of the fly ash.

3.4.3 BRAZILIAN TEST (ASTMD 3967)

The tensile strength is determined by indirect method called Brazilian test.

Procedures: Core specimens with length-to-diameter ratios (L/D) of 0.5 are placed in a compression loading machine. The maximum load (P) to fracture the specimen is recorded and used to calculate the split tensile strength.

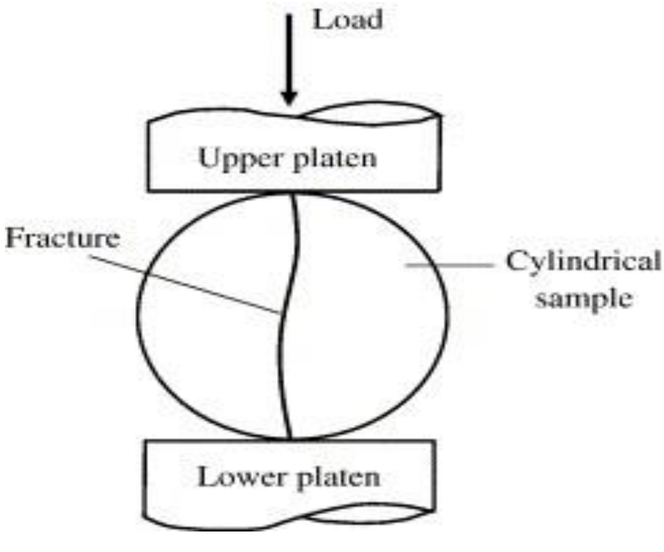

Figure 3.3: Setup for Brazilian tensile test in standard loading machine

The samples were placed diametrically during test. The sample fails diametrically in tension by application of load. The indirect tensile strength is calculated as:

$$\sigma_t = \frac{2P}{\pi D t}$$

Where

σ_t= Brazilian Tensile Strength

P = Failure Load

D = Diameter of the sample

t = thickness of the sample

3.4.4 TRIAXIAL COMPRESSION TEST

The un-drained, triaxial compression test was carried out as per IS: 2720-Part 11 (1993) to determine the shear strength parameters of flyash composite material. Three identical samples of 38 mm diameter and 76 mm length, one each of flyash-lime, flyash-gypsum and flyash-cement composite material were prepared. The samples were tested by giving confining pressures $1kg/cm^2$, $2kg/cm^2$ and $3kg/cm^2$ respectively. Mohr-Coulomb relation between two normal stresses (τ = C+ σ_n tan φ) has been used to determine Cohesion (c) and angle of internal friction (φ)of the materials. σ_n is the effective normal stress.

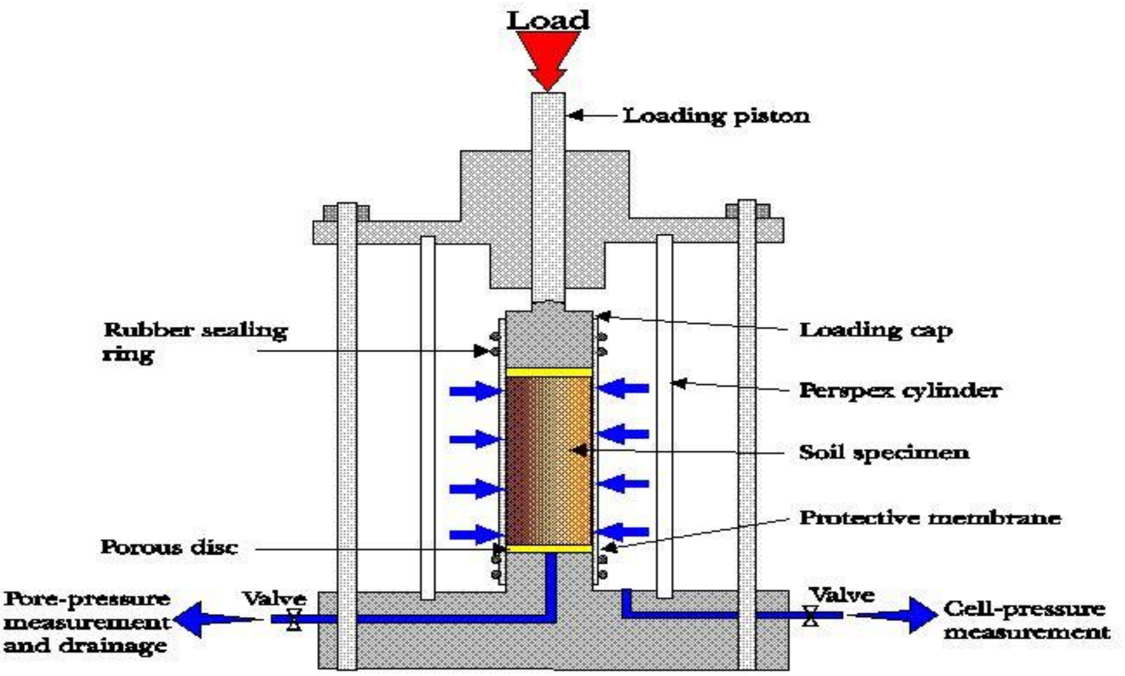

Figure 3.4: Triaxial apparatus (http://environment.uwe.ac.uk)

3.4.5 ULTRASONIC PULSE VELOCITY TEST

P-wave velocity values of developed composites were determined using an Ultrasonic Velocity Measurement System (make: GCTS, USA). The test was carried out by applying two sensors opposite to the surfaces of the specimen. To maintained sufficient surface contact between the sensors and the specimen honey was used as a couplant (Figure 3.5).

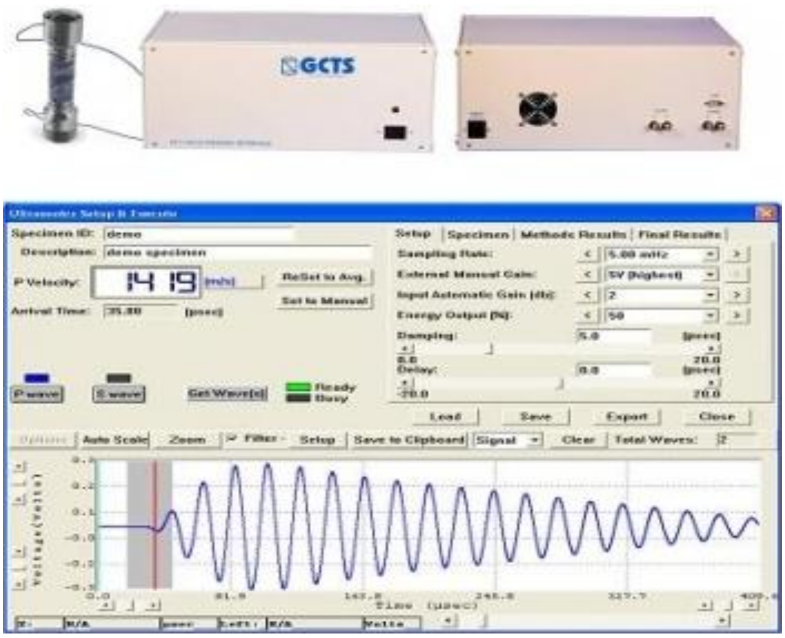

Figure 3.5: Typical Ultrasonic velocity measurement device (www.gcts.com)

The relationship between various parameters on density, pulse velocity, elastic constants, modulus values are given by the following equations

$$\mu = \frac{v_P^2 - zv_s^2}{2(v_P^2 - v_s^2)}$$

$$E = \frac{\rho v_s^2(v_P^2 - 4v_s^2)}{v_p^2 - v_s^2}$$

$$K = \frac{\rho\left(v_p^2 - 4v_S^2\right)}{3}$$

$$G = \rho v_s^2$$

Where,

V_p= compression P wave velocity, m/s

Vs= shear S wave velocity, m/s

ρ= density, kg/m3

μ= Poisson's ratio

E= Young's Modulus, Pa

K= Bulk Modulus, Pa

G= Shear (Rigidity) Modulus, Pa

Chapter 4: Result and discussion

4.1 INTRODUCTION

The aim of the study was develop a composite material using flyash, lime, gypsum and cement which can be an alternative to sand backfilling of mines. Backfilling is done to reduce the surface subsidence problem created by the voids due to underground mining. The fly ash was added with cement, gypsum and lime to enhance its pozzolanic properties. The results of the test conducted are reported here.

4.2 COMPACTION TEST

The optimum moisture content was 30% and the dry density was found out to be 1.208 g/cm^3

Density determination

Mold volume = 996.95 cm^3

Mass of the mold =3.694 kg

Table 4.1: Water content determination

Water added	16%	20%	24%	28%	32%	36%
Mass of empty container(gm)	20	20	20	11	13	11
Mass of container+ flyash (moist)	67	88	85	73	52	61
Mass of container+ dry flyash(gm)	61	77	73	60	43	48
Mass of dry flyash (gm)	41	57	53	49	30	37
Mass of pore water(gm)	6	11	12	13	9	13
%water content	14.6	19.3	22.6	26.5	30.0	35.1

Table 4.2: Dry density determination

Sample No	1	2	3	4	5	6
Assumed water %	16	20	24	28	32	36
Actual avg water content %	14.6	19.3	22.6	26.5	30	35
Mass of fly ash+mold (kg)	4.985	5.056	5.128	5.212	5.222	5.180
Mass of wet flyash(kg)	1.291	1.362	1.434	1.518	1.528	1.486
Wet density(gm/cm^3)	1.295	1.366	1.438	1.523	1.533	1.490
Dry density(gm/cm^3)	1.130	1.145	1.170	1.204	1.180	1.103

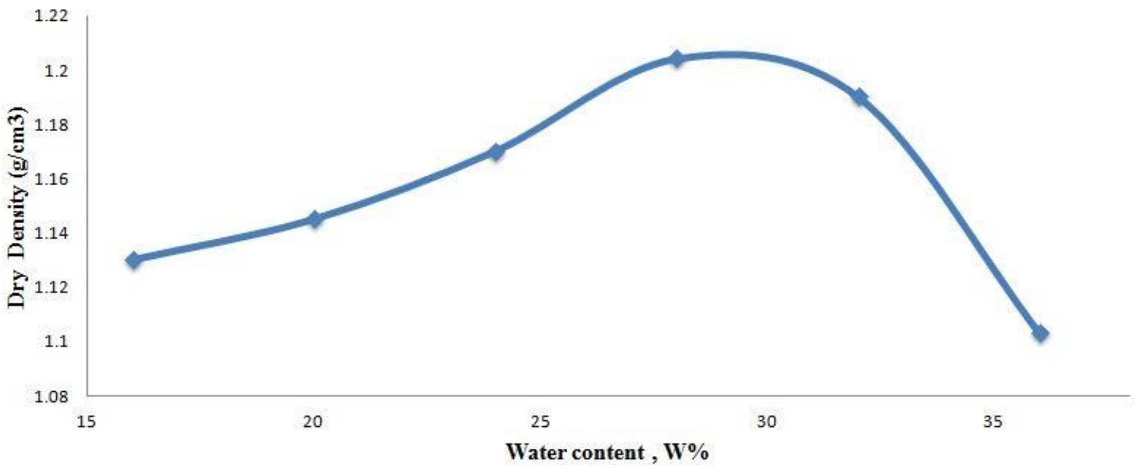

Figure 4.1: Graph between Dry density and Water content

It shows as the moisture content increases, Maximum dry density increases. The optimum moisture content was found out to be 30 % at maximum dry density of 1.208 gm/cm^3 Figure 4.1).

4.3 SLUMP CONE TEST

Slump test in an inexpensive method to predict the flow behavior of the flyash composite. The spread the material is determined from it. The maximum slump height of flyash composite material was found out to be 110 m using flyash-gypsum composite material, whereas the lowest slump height of was found out in flyash-cement composite material which was 70mm (figure 4.3). Cement based composite exhibited better result as it is not only a stronger material but also binds fly ash particles more than that were observed with gypsum and lime.

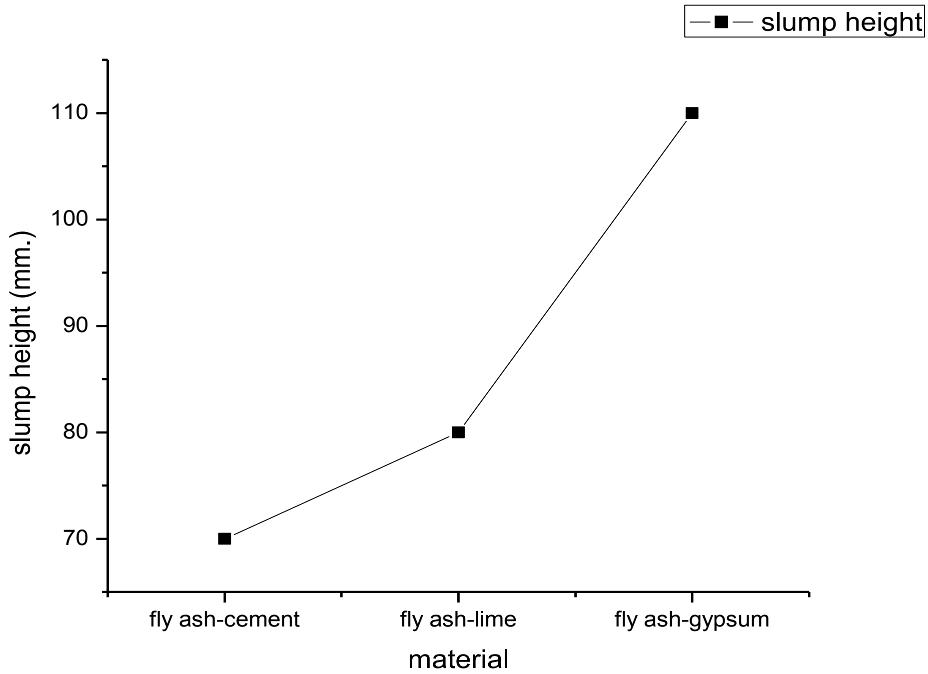

Figure 4.2: Slump height vs. fly ash composite material

Figure 4.3: slump height of flyash-cement composite material.

4.4 BRAZILIAN TENSILE STRENGTH

Tensile strength is a determination of resistance of the composite to external tensile forces. Brazilian indirect tensile strength tests were carried out to determine the tensile strength of the fly ash composites in the same testing machine used to find the compressive strength.

The samples for the test measured 60 mm in diameter and 30 mm in thickness were cut from the specimen prepared for ultrasonic pulse velocity tests. The samples were loaded along the diametrical axis as followed in the method. It was observed that the tensile strength of samples with 4 % lime , 4% gypsum and 4 % cement were 0.10 MPa,0.15 MPa and 0.60 Mpa respectively(Figure 4.4). All the samples failed in less than 110secs.

Figure 4.4: Failure profile of different fly ash composite material

4.5 TRIAXIAL COMPRESSION TEST

Triaxial test is conducted to determine the behavior of material under confinement. The cohesion and fractional angle of flyash composite material was found out to be given in table 4.3:

Table 4.3: Cohesion and Friction angle of different fly ash composite material

Composite materials	Cohesion (MPa)	Friction angle(deg)
Flyash-lime	0.828	26.87
Flyash-gypsum	0.574	27.73
Flyash-cement	1.174	29.07

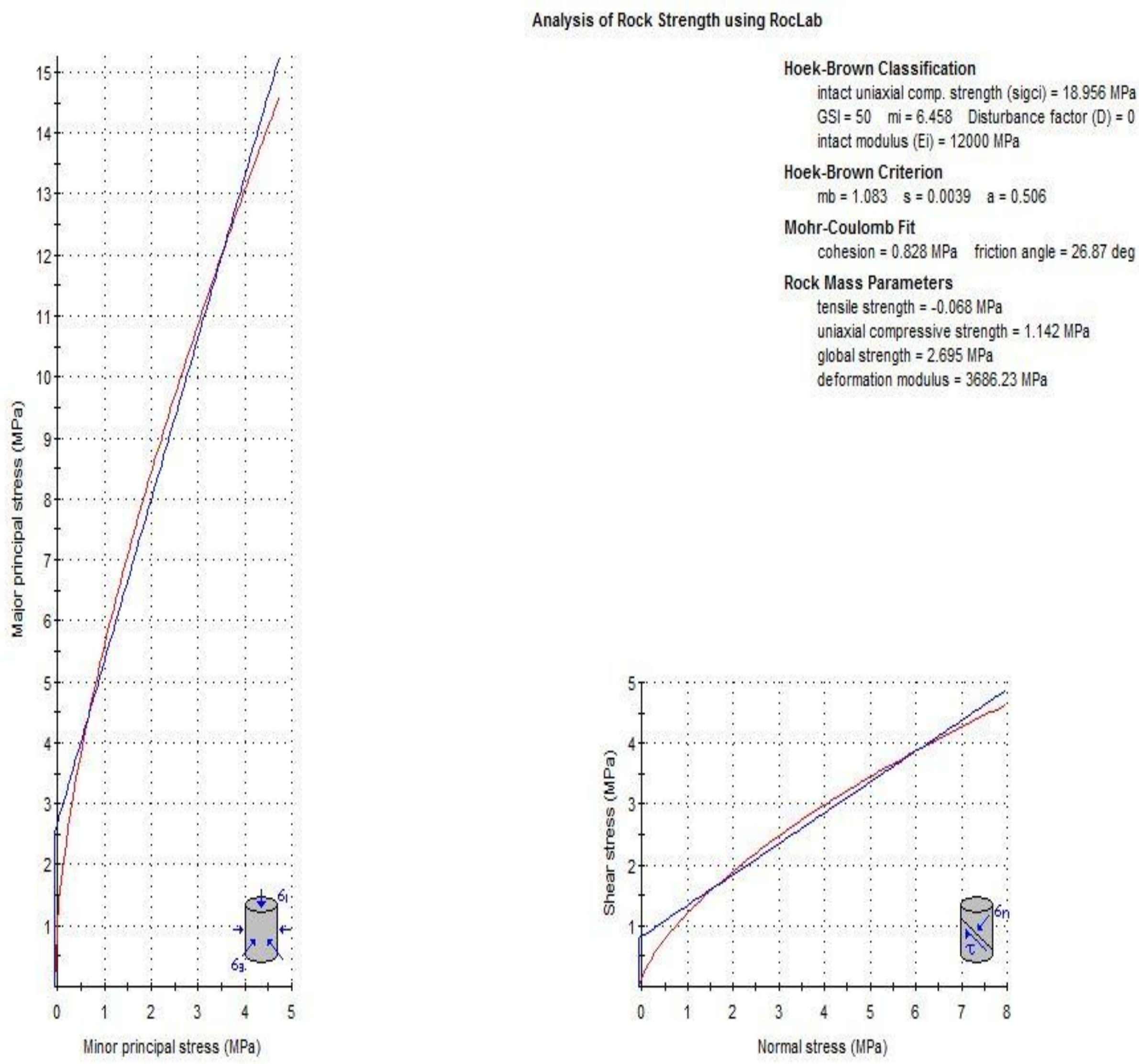

Figure 4.5: Triaxial characteristic of flyash-lime composite material

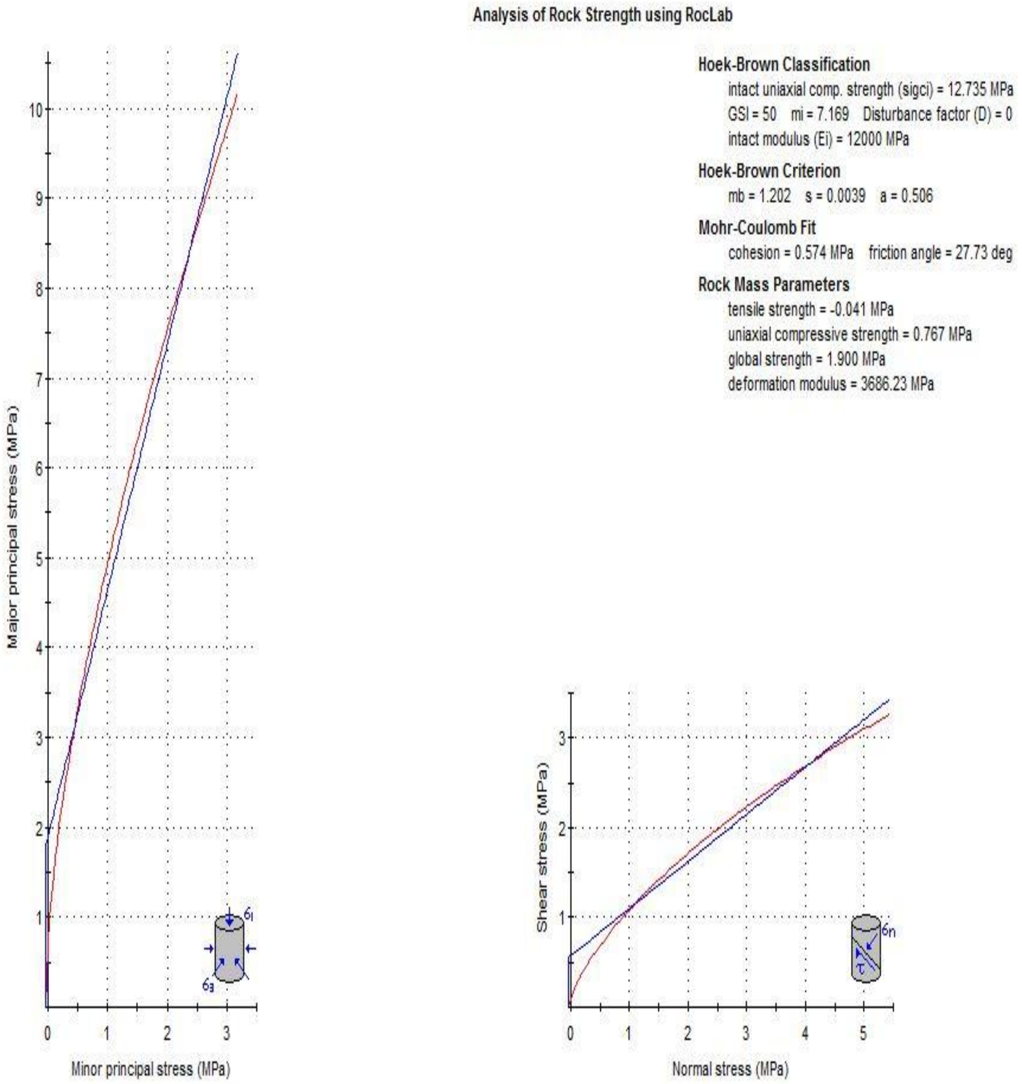

Figure 4.6: Triaxial characteristic of fly-ash gypsum composite material

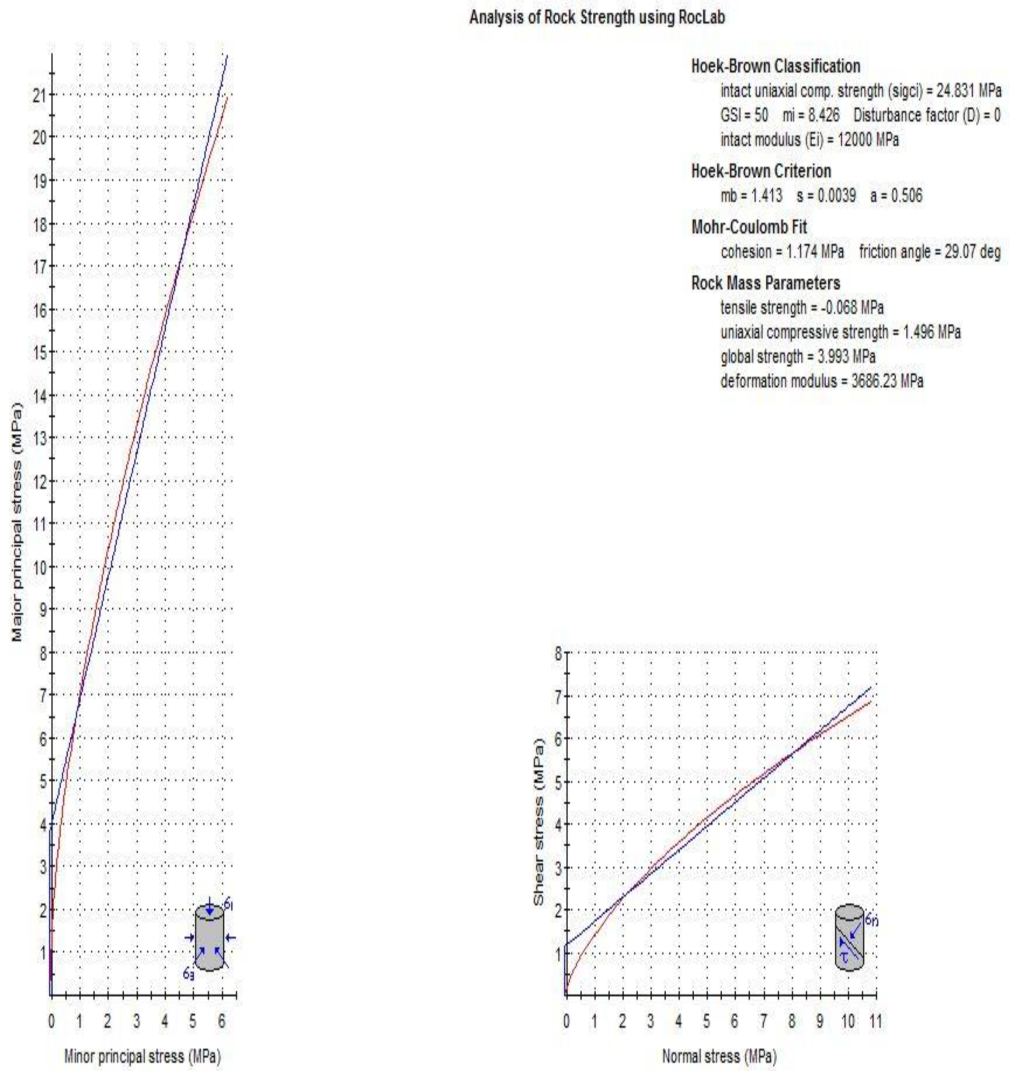

Figure 4.7: Triaxial characteristic of Flyash –cement composite material

4.6 ULTRASONIC PULSE VELOCITY TEST

The P-wave velocity depends on the quality of cohesiveness of constituent materials, transmission, dampness, presence of weaknesses as crack, voids, etc. Its precision also depends on the homogeneity of the sample. The P wave velocities of untreated fly ash-overburden composites did not exhibit any significant strength values.

The ultrasonic pulse velocities varied between 753 m/s and 1527 m/s for varying curing periods. Highest values were obtained at 28 days curing, thus confirming the increased conductivity in the sample (Figure 4.4). The conductivity is a result of enhanced pozzolanic reaction due to enhanced reaction between alumina (Al_2O_3), calcium oxide (CaO), and silica (SiO_2). The maximum P wave velocity values were obtained for the composite 96%FA +4%cement. P wave velocities obtained at 7, 14, 28 days curing were between 753 and 1027 m/s, 785 and 1217 m/s, 912 and 1527 m/s respectively .

Table 4.4: Dynamic properties of fly ash

Parameters	FA +lime(4%)	FA +gypsum(4%)	FA+cement (4%)
Density(kg/m^3)	1365	1277	1534
Young's modulus (MPa)	157.6	185.2	220.3
Bulk modulus (MPa)	175.1	220.5	306.0
Shear modulus (MPa)	58.4	68.0	79.8
Poisson ratio	0.35	0.36	0.38

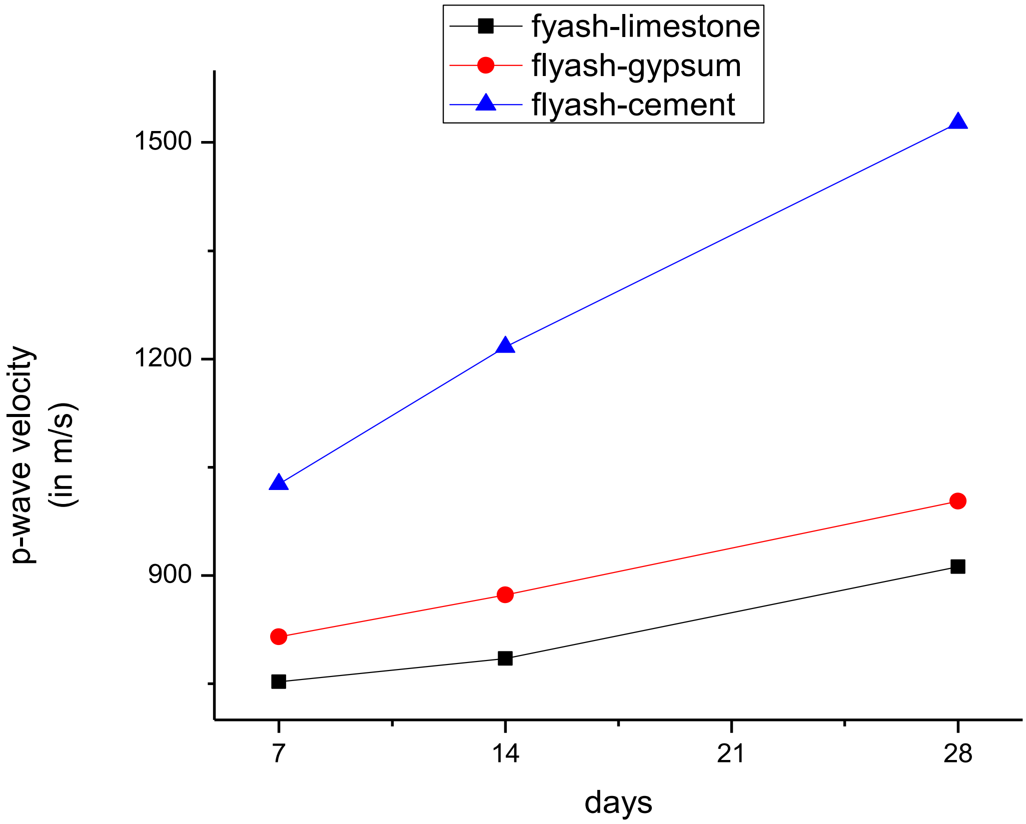

Figure 4.8: P-wave velocity of flyash–lime, flyash-gypsum and flyash-cement composite material

It shows that fly ash–cement composite material has bonded better as compared to other two materials. The p-wave value also increased at high rate with increasing in curing time for flyash –cement as compare to the other two composite material.

Chapter 5: Numerical Investigation

5.1 Numerical Investigation

FLAC is a two-dimensional explicit finite difference program for engineering mechanics calculation. This program simulates the behavior of structures built of soil, rock or other materials. That may undergo plastic flow when their yield limits are reached. Materials are represented by zone or elements, which form a grid that is adjusted by the user to fit the shape of the object to be modeled. Each element behaves according to a prescribed linear or nonlinear stress/strain law in response to the applied forces or boundary restraints. The material can yield and flow and the grid can deform and move with the material that is represented. The explicit, Lagrangian calculation scheme and the mixed-discretization zoning technique used in FLAC ensure that plastic collapse and flow are modeled very accurately. Because no matrices are formed, large two-dimensional calculations can be made without excessive memory requirements. The drawbacks of the explicit formulation are overcome to some extent by automatic inertia scaling and automatic damping that do not influence the mode of failure.

Though FLAC was originally developed for geotechnical and mining engineers, the program offers a wide range of capabilities to solve complex problems in mechanics. Several built-in constitutive models that permit the simulation of highly nonlinear, irreversible response representative of geologic, or similar, materials are available. In addition, FLAC contains many special features including:

- Interface elements to simulate distinct planes along which slip and/or separation can occur
- Plane-strain, plane-stress and axisymmetric geometry modes
- Groundwater and consolidation models with automatic phreatic surface calculation
- Structural element models to simulate structural support
- Extensive facility for generating plots of virtually any problem variable
- Optional dynamic analysis capability
- Optional viscoelastic and viscoplastic models
- Optional thermal (and thermal coupling to mechanical stress and pore pressure modeling capability
- Optional two-phase flow model to simulate the flow of two immiscible fluids through a porous medium

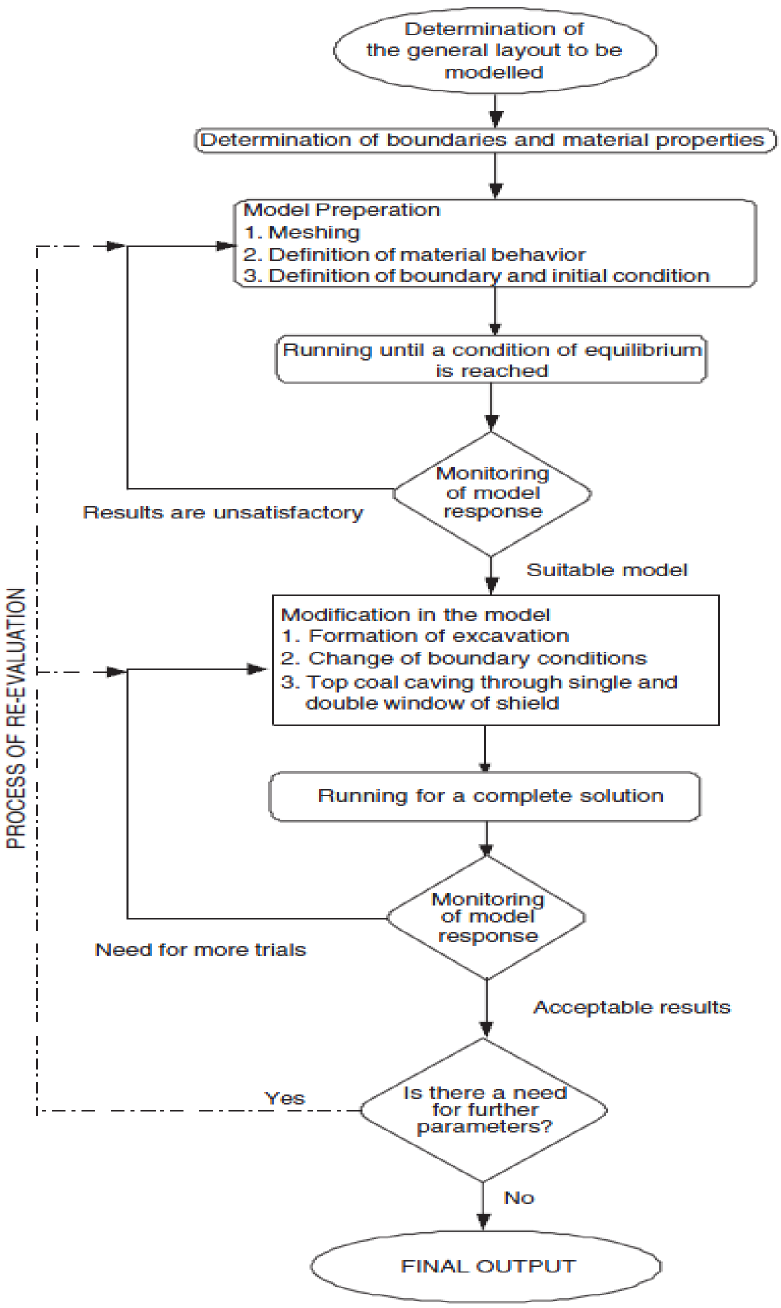

Figure 5.1: Flow chat of modeling procedure [15]

Geo-mining condition of a nearby underground coal mine was considered for study of effect of backfilling. Geo-mining condition of the mine was modeled and simulated for different mixture of flyash with limestone, gypsum and cement to assess the strata stability. The parameters considered for the numerical analyses are given in table 5.1. The geo-mining condition modeled is given in Table 5.2.

Table 5.1: Properties of coal

Property	Coal	Sandstone
Bulk Modulus	3.67 GPa	6.67 GPa
Shear Modulus	2.2 GPa	4.0 GPa
Density	1427 kg/m^3	2300 kg/m^3
Tensile Strength	1.86 MPa	9.0 MPa
Cohesion	1.85 MPa	12.0 MPa
Friction Angle	30^0	45^0

Table 5.2: Geo-mining condition of the mine

Parameters	Values
Thickness of seam	11 m
Width of the development gallery	4.2 m
Height of the development gallery	3.0 m
Size of the Panel	150m x 120m
Area of the Panel	16000 m^2
No. of Pillars	6
No. of Rooms	9
Depth	323 m
Average size of pillars (m2)	60 X 50
Gradient of the seam	1 in 5.5
Total Coal in the Panel	283000 T

Table 5.3: Engineering properties of flyash composite material (FCM)

Parameters	FA+lime(4%)	FA +gypsum(4%)	FA +cement (4%)
Density(kg/m^3)	1365	1277	1534
Young's modulus (MPa)	157.6	185.2	220.3
Bulk modulus (MPa)	175.1	220.5	306.0
Shear modulus (MPa)	58.4	68.0	79.8
Poisson ratio	0.35	0.36	0.38
Cohesion (MPa)	0.890	0.574	1.17
Friction angle	26.0	27.7	30.2
Tensile strength (MPa)	0.10	0.15	0.60

The model anlyses were carried out for various combination and situations with and without fly ash filling. Maximum vertical deformation observed in the gallery next to goaf edge without backfilling was 100 mm (Figure 5.2).

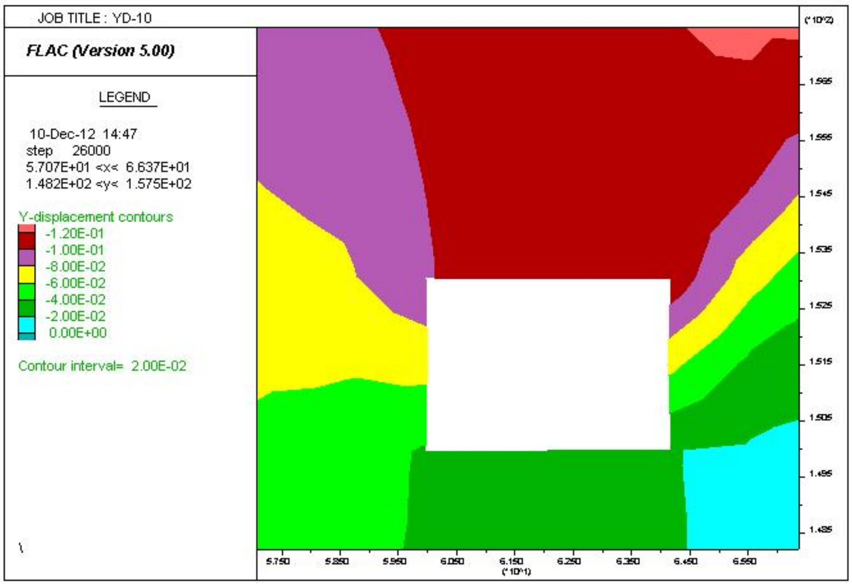

Figure 5.2: Vertical Deformation in the gallery next to goaf edge without backfilling.

Maximum vertical deformation observed in the gallery next to goaf edge after backfilling with mixture of flyash with 4% limestone was 12.5 mm (Figure 5.3).

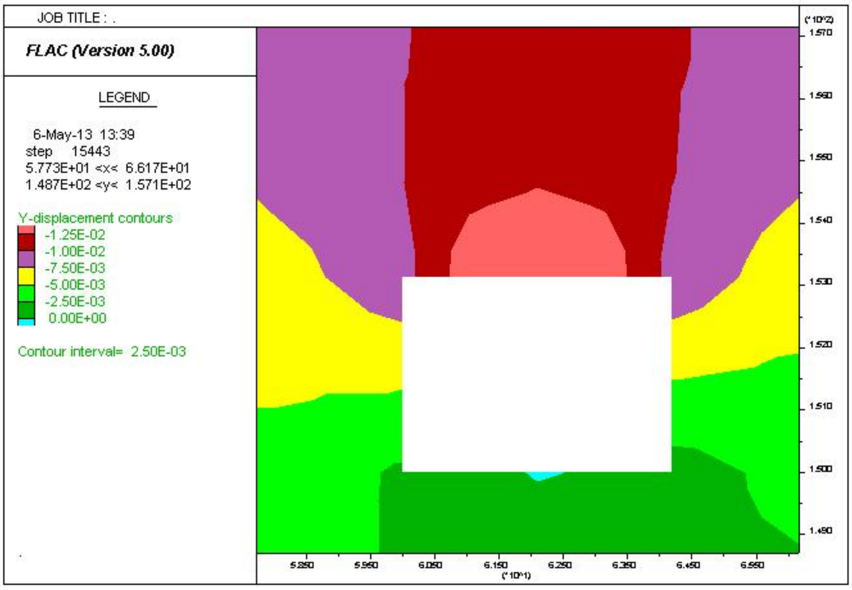

Figure 5.3: Vertical Deformation in the gallery next to goaf edge after backfilling with mixture of flyash with 4% limestone.

Maximum vertical deformation observed in the gallery next to goaf edge after backfilling with mixture of flyash with 4% gypsum was 12.5 mm (Figure 5.4).

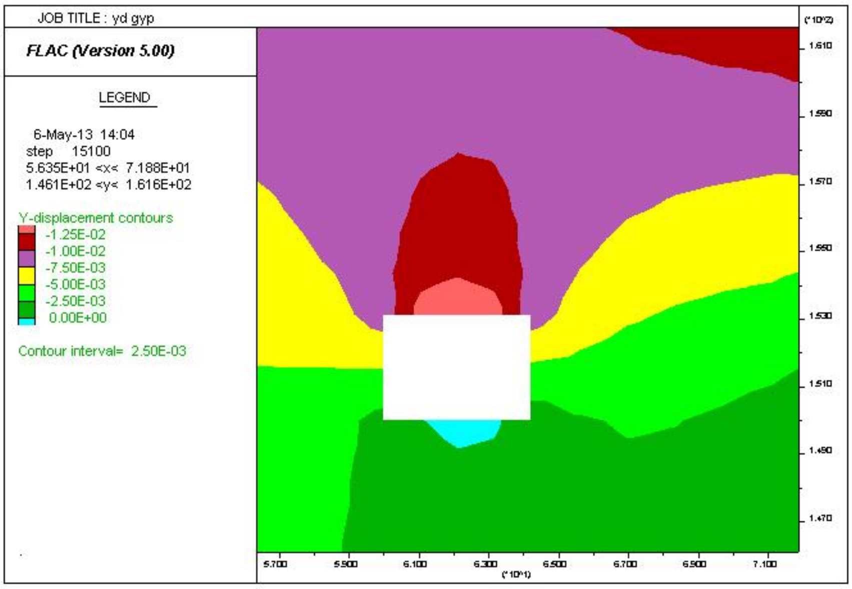

Figure 5.4: Vertical Deformation in the gallery next to goaf edge after backfilling with mixture of flyash with 4% gypsum.

Maximum vertical deformation observed in the gallery next to goaf edge after backfilling with mixture of flyash with 4% cement was 10 mm (Figure 5.5).

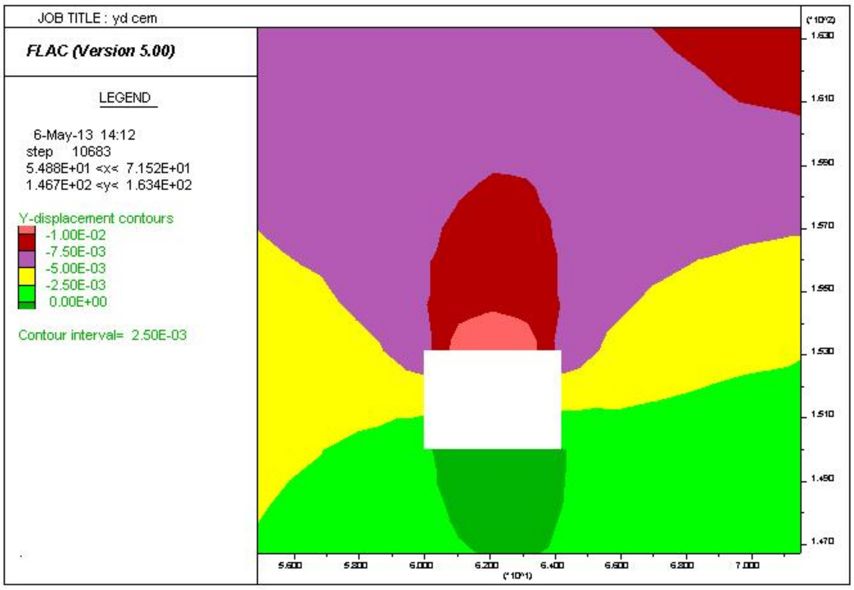

Figure 5.5: Vertical Deformation in the gallery next to goaf edge after backfilling with mixture of flyash with 4% cement.

Maximum vertical stress developed over the goaf after backfilling with mixture of flyash with 4% limestone after simulation was 5 MPa (Figure 5.6).

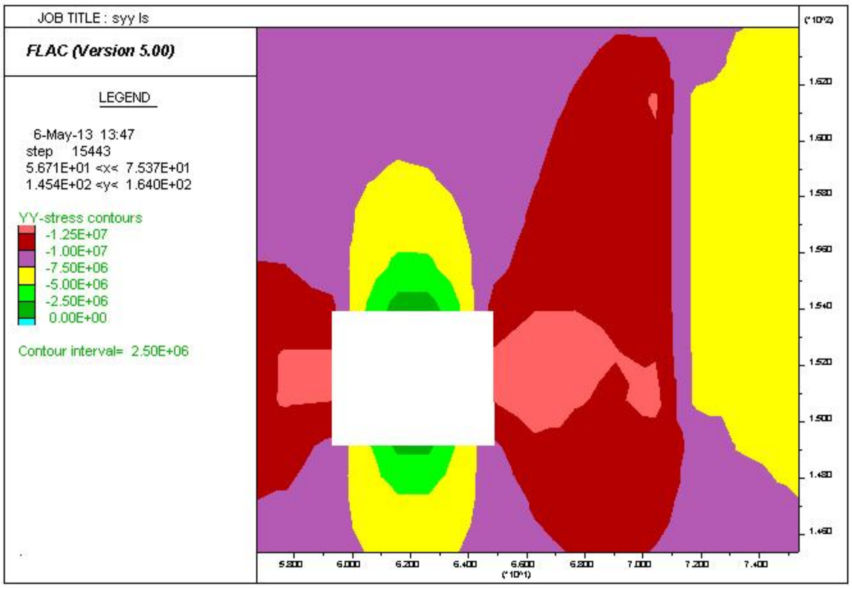

Figure 5.6: Vertical stress developed over the goaf after backfilling with mixture of flyash with 4% limestone.

Maximum vertical stress developed over the goaf after backfilling with mixture of flyash with 4% gypsum after simulation was 5 MPa (Figure 5.7)

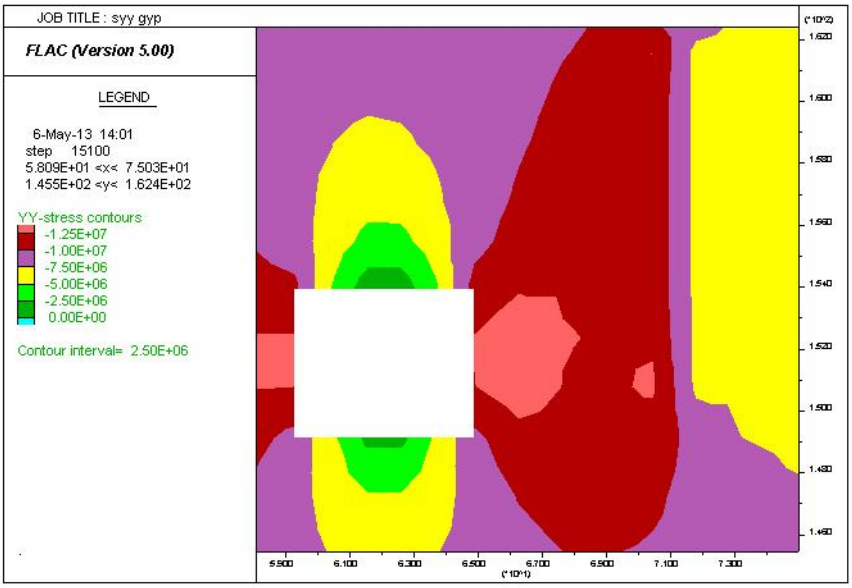

Figure 5.7: Vertical stress developed over the goaf after backfilling with mixture of flyash with 4% gypsum.

Maximum vertical stress developed over the goaf after backfilling with mixture of flyash with 4% cement after simulation was 4 MPa (Figure 5.8)

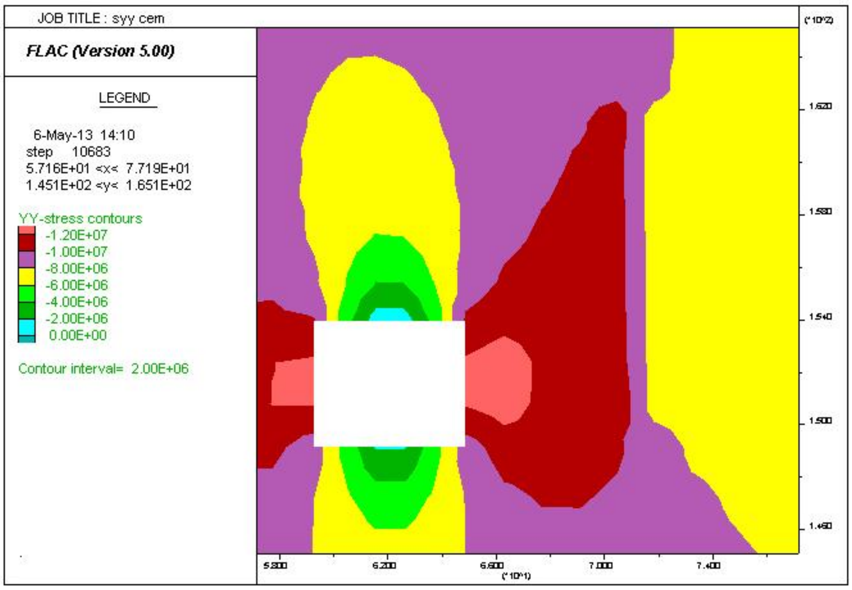

Figure 5.8: Vertical stress developed over the goaf after backfilling with mixture of flyash with 4% cement.

Maximum horizontal stress developed around the goaf after backfilling with mixture of flyash with 4% limestone after simulation was 2.5 MPa (Figure 5.9).

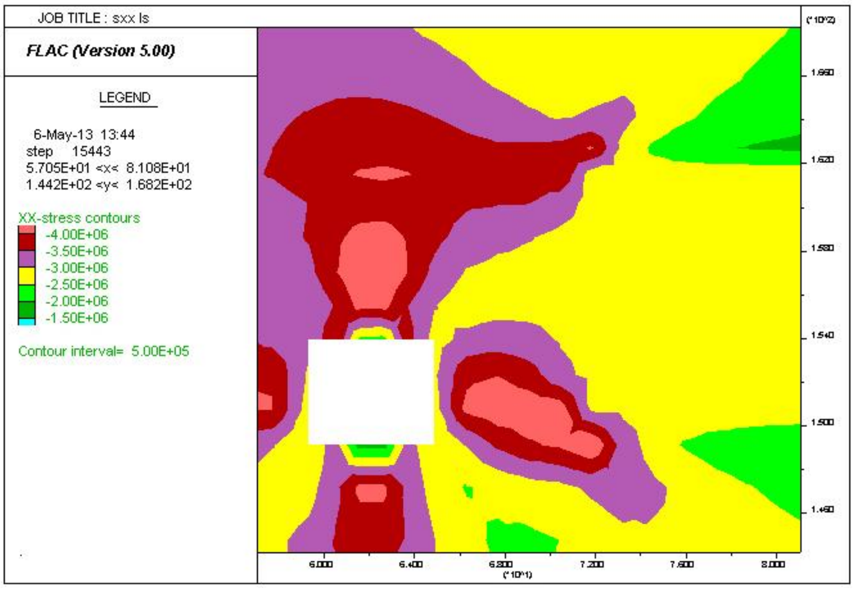

Figure 5.9: Horizontal stress developed around the goaf after backfilling with mixture of flyash with 4% lime.

Maximum horizontal stress developed around the goaf after backfilling with mixture of flyash with 4% gypsum after simulation was 2.5 MPa (Figure 5.10).

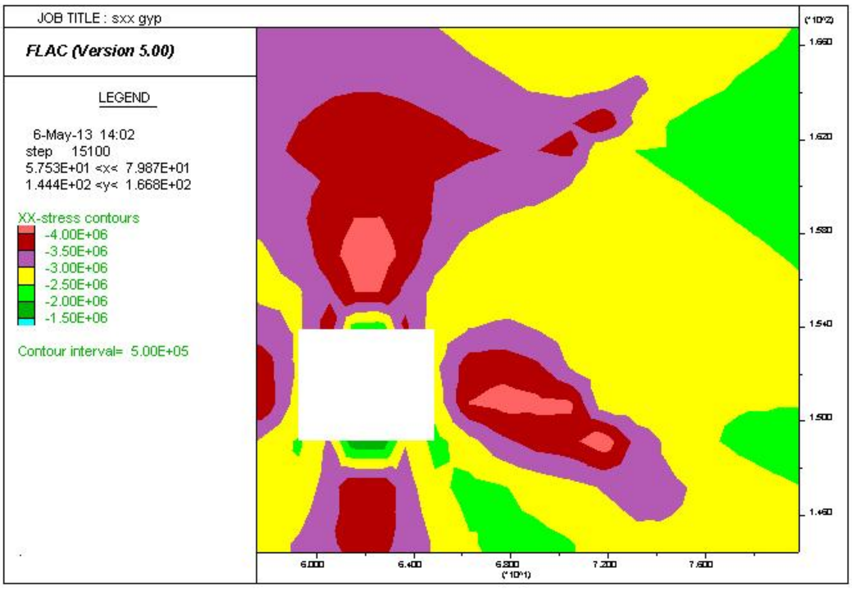

Figure 5.10: Horizontal stress developed around the goaf after backfilling with mixture of flyash with 4% gypsum.

Maximum horizontal stress developed around the goaf after backfilling with mixture of flyash with 4% cement after simulation was 2 MPa (Figure 5.11)

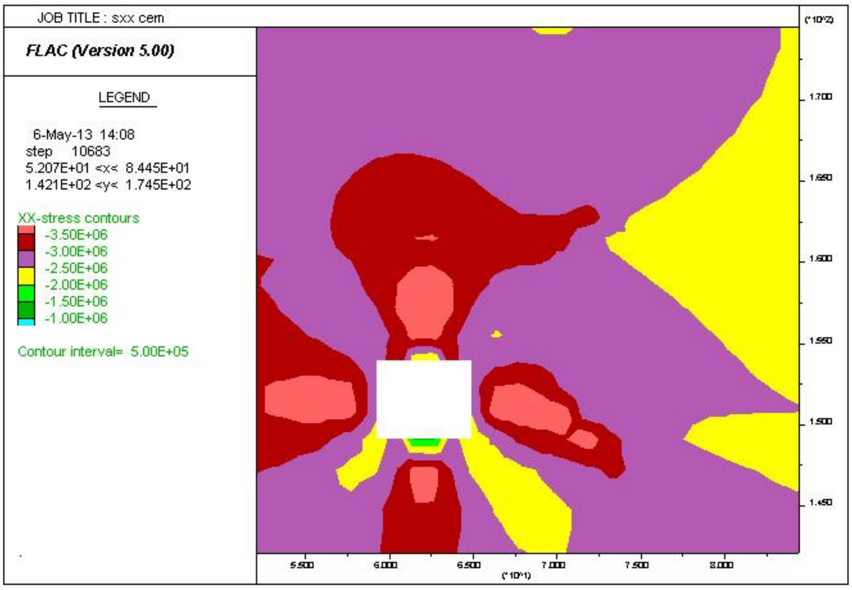

Figure 5.11: Horizontal stress developed around the goaf after backfilling with mixture of flyash with 4% cement.

The vertical stresses developed after excavation was found out to be 15 MPa. The stress value reduces dramatically when the analyses are carried out with fly ash composite material filling. The flyash- cement composite material produced the least stress value at 5 MPa (Figure 5.12)

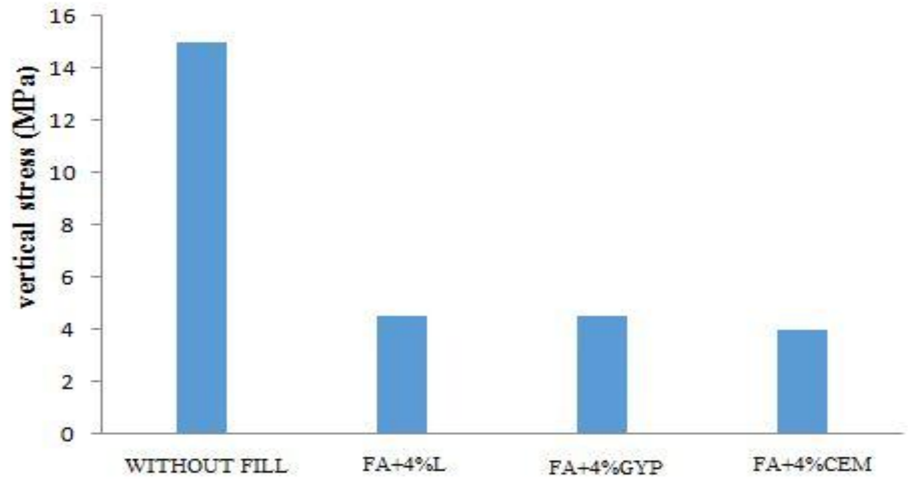

Figure 5.12: Effect of different composite backfilling material on vertical stress

The horizontal stress developed after excavation was found out to be 7.5 MPa. The stress value reduces dramatically when the analyses are carried out with fly ash composite material filling. The flyash- cement composite material produced the least stress value at 2 MPa (Figure 5.13)

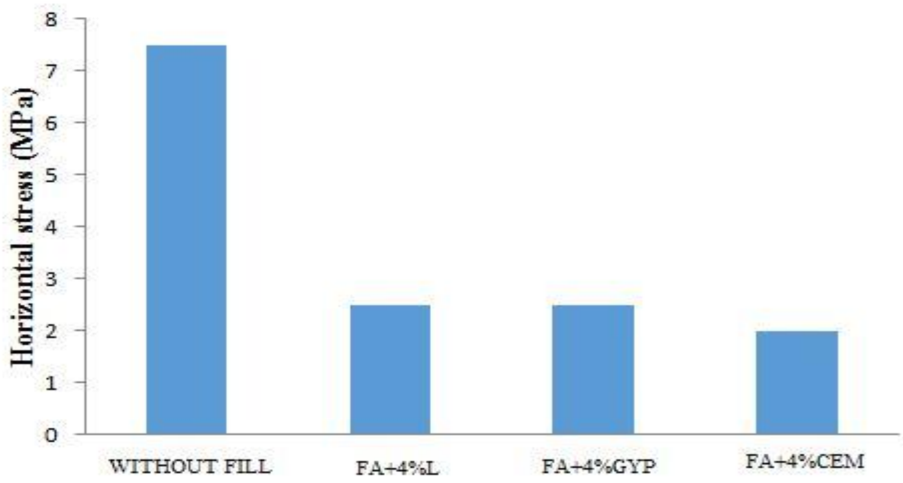

Figure 5.13: Effect of different composite backfilling material on Horizontal stress

The vertical deformation was found out to be 100 mm after excavation. It reduces to 10 mm after backfilling with flyash – cement composite material (Figure 5.14).

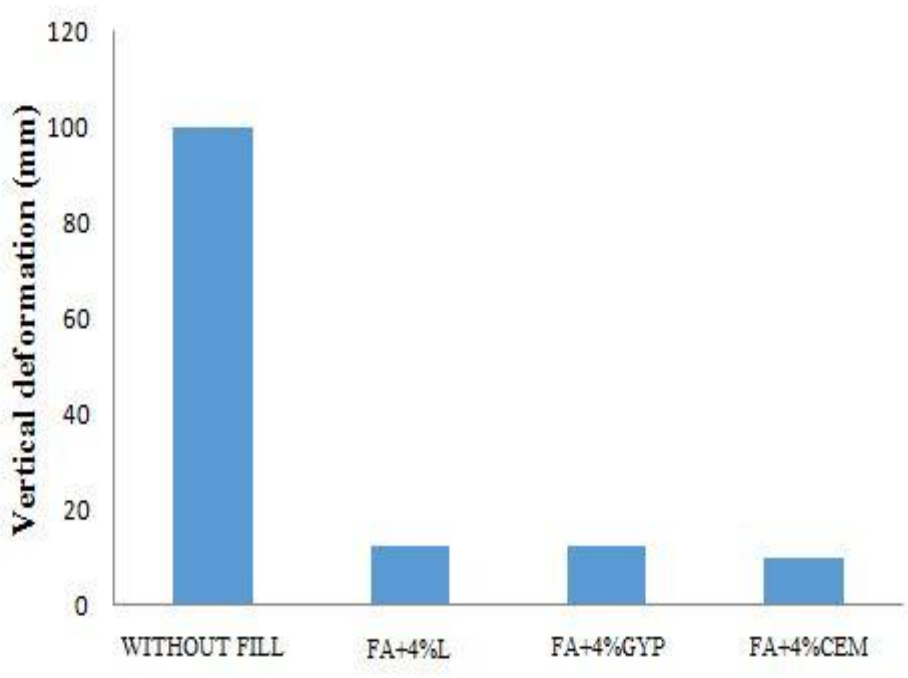

Figure 5.14: Effect of different composite backfilling material on vertical deformation

CONCLUSION

The aim of the present investigation was to study the engineering properties of the developed fly ash composite materials as an alternative to sand as a backfilling material. The fly ash composite developed with the addition of lime, gypsum and cement have enhanced the strength characteristic of the fly-ash.

The loose sand as a backfill material merely occupies the underground space created by the mining operation and studies in the past have also indicated that they provide no lateral stresses to support the stability of the opening. The following conclusions were drawn from the investigation.

1. The fly ash is of class F without any self-cementing properties, but posses pozzolanic properties.
2. Its optimum moisture content was 30% and dry density was 1.208 gm/cm^3.
3. Maximum slump height was found out to be 110 mm in fly ash-gypsum and minimum in fly ash-cement of 70 mm.
4. Maximum tensile strength was found out to be 0.6 MPa in fly ash-cement and minimum was found out to be 0.1 MPa in fly ash-lime.
5. Ultrasonic pulse velocity test showed that the strength of the composite increases with increases in curing time.
6. Backfilling with fly ash composite showed decreases in vertical stresses, horizontal stress as well as in vertical deformation.
7. Use of fly ash composite material reduces vertical stress to 5MPa from 15 MPa and horizontal stress to 2 MPa from 7.5 MPa. Similarly vertical deformation reduces to 10mm from 100 mm.
8. Fly ash-cement composite exhibits best characteristic as compare to lime and gypsum
9. All the three composite posses excellent backfilling attributes.

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The major conclusion of the study was that the fly ash from nearby thermal power plant has greater potential to be developed into a strong engineering material with the addition of lime, gypsum and cement.

6.1 RECOMMENDATION FOR FUTURE WORK

The aim and objectives of the current investigation were limited to laboratory analysis. It is recommended to investigate the following for a better understanding of the subsidence control and stress distribution in mines.

1. Fly ash composite with varying percentage of lime, gypsum and cement should be examined to evaluate their geo-technical properties.
2. More experiments should be carried out to modify the settling properties of fly ash composite materials either with conventional or new alternatives.
3. Long term effects of fly ash composite should be evaluated in actual field condition.

REFERENCE

1. Mishra M.K. and Rao K.U.M., Geotechnical Characterisation of Fly ash Composites for Backfilling Mine Voids. Journal of Geotech and Geol Eng, 24 (2006): pp. 1749-1765.

2. Ahmaruzzaman M., “A review on the utilization of fly ash”, Journal of Progress in Energy Combust. Sci., 36 (2010): pp. 327-363.

3. Mishra M.K., “Experimental and Numerical analysis of behaviour of model pillars trapped with reinforced fly ash composites”, Ph.D thesis, Indian Institute of Technology, Kharagpur, India, 2003.

4. Behera R.K, Characterization of Fly ash for their Effective Management and Utilization, B.Tech thesis, National Institute of Technology, Rourkela, India ,2010

5. Yamatami J. and Kotake Y., “Pillar control and effects of backfilling support at Osaka mine”, International journal of rock mechanics, mining science and geomechanics,1986, Vol. 23, No.2, pp. 44-53

6. Chugh, Y.P., D. Biswas, D. Deb and G. Deaton (2001) Underground placement of coal processing waste and coal combustion byproducts based paste backfill to enhance mining economics. ICCI No. 97, US1, p 52

7. Singh R.D . Principle and Practices of Modern Coal Mining . New Delhi : New Age International, 2011

8. Mallick S.R, Development and Evaluation of Clinker Stabilized Fly Ash Based Composite Material for Haul Road Application, M.Tech thesis, National Institute of Technology, Rourkela, India, 2012

9. DiGioia, A. M. and Nuzzo, W. L. (1972) Fly ash as structural fill, Journal of Power Div.,ASCE, vol. 98 (1), 77-92

10. Das A, Strength Characterization of Fly ash Composite Material, B.Tech thesis, National Institute of Technology, Rourkela, India ,2009

11. Fawconnier, C.J. and Korsten, R.W.O. (1982) Ash fill in pillar design- Increased Underground Extraction of Coal, The SAIMM Monograph Series 4, pp 277 –361

12. Galvin, J.M. and Wagner, H. (1982) Use of ash to improve strata control in bord and pillar working, in Proceed. Symposium on Strata Mechanics, Univ. of Newcastle upon Tyne, pp264-269

13. Grice, T. (1998) Underground Mining with Backfill 2nd Annual Summit, Mine Tailings Disposal System, Brisbane, Nov 24-25, pp 1-13

14. IS:100080-1981 (1982) Method of tests for determination of tensile strengths by indirect tests on rock specimen, UDC 691.2:620.172, November, ISI New Delhi, pp 1-13

15. Pandian N.S., Fly ash characterization with reference to geotechnical applications, Journal of Indian Inst. of Sc., 84 (2004): pp. 189-216.

16. Prabakar J., Dendorkar N. and Morchhale R.K., Influence of fly ash on strength behavior of typical soils, Journal of Construction and Building Materials, 18 (2004): pp.263-267.

17. Baker M.D. and Laguros J.G., Reaction products in fly ash concrete, Fly ash and coal conversion by-products: characterisation, utilisation and disposal, G.J. MaCarthy, F.P. Glasser and D.M. Royeds, Materials Research Society, Pittsburgh, 43 (1985): pp. 73-83.

18. Dimter S., Rukavina T. And Barisic I.,Application of the ultrasonic method in evaluation of properties of stabilized mixes, The Baltic Journal of Road and Bridge Engg., 6(2011): pp. 177-184.

19. Fast Lagrangian Analysis and Continua (FLAC) Manual, Version 5, Second Edition, April 2005 by Itasca

20. http://freepdfdb.com/pdf/opportunities-amp-challenges-in-fly-ash-utilization-in indian-49830037.html

21. http://freepdfdb.com/pdf/fly-ash-generation-and-utilization-an-overview-by 14833747.html